AD-A036 661 NAVY EXPERIMENTAL DIVING UNIT PANAMA CITY FLA F/G 13/9

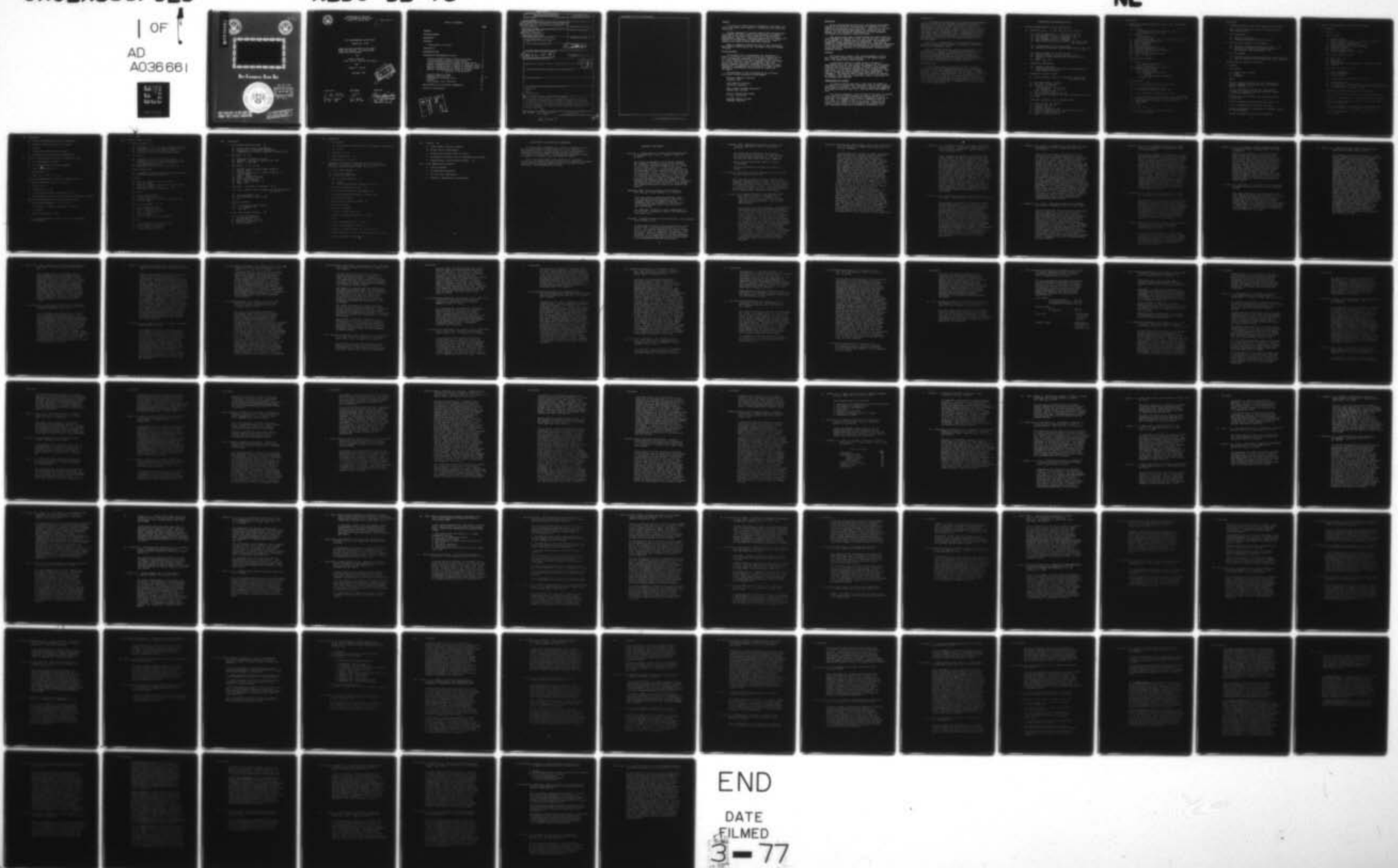
HUMAN FACTORS INFORMATION FOR UNDERWATER TOOL DESIGN: AN OUTLIN--ETC(U)

DEC 76 F B BARRETT, R C CARTER

UNCLASSIFIED NEDU-12-76 NL

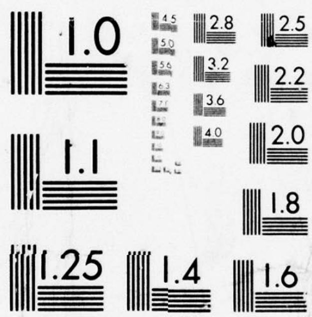
1 OF 1

AD
A036661



END

DATE
FILMED
3-77



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD A036661

NAVY EXPERIMENTAL DIVING UNIT

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32401

IN REPLY REFER TO:

1

NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 12-76

HUMAN FACTORS INFORMATION FOR UNDER-WATER TOOL DESIGN: An Outline and Annotated Bibliography

By:

Fred B. Barrett
Naval Coastal Systems Laboratory

and

Robert C. Carter

December 1976

47

Submitted:

ROBERT C. CARTER
LT MSC USN

Reviewed:

W. H. SPAUR
CAPT MC USN

Approved:

J. MICHAEL RINGELBERG
CDR USN
Commanding Officer

TABLE OF CONTENTS

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NEDU REPORT 12-76	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) HUMAN FACTORS INFORMATION FOR UNDERWATER TOOL DESIGN: AN OUTLINE AND ANNOTATED BIBLIOGRAPHY.		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) FRED B. BARRETT ROBERT C. CARTER		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS NAVY EXPERIMENTAL DIVING UNIT PANAMA CITY, FLORIDA 32407		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS	(11)	12. REPORT DATE DECEMBER 1976
		13. NUMBER OF PAGES 62
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (14) NEDU-12-76		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited. (12) 87p.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

UNDERWATER
TOOLS
DIVING
HUMAN FACTORS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An annotated bibliography was assembled of material related to design of tools for use by undersea divers. The material was related to topics in an outline of information requirements for tool design. The outline and bibliography enable the user to find information relevant to any particular underwater tool design problem.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

253650

SUMMARY

An outline of human factors information requirements for diver tool design was prepared in conjunction with other Navy facilities.

Library searches for related reports were conducted and all possible pertinent reports were obtained and studied. Summaries of the reports are contained in the Annotated Bibliography (page 14). Reference numbers for all reports are entered in the Information Requirements Outline (page 4) opposite the items to which they were relevant.

Data is presently lacking for many of the information requirements, particularly for individual tools and classes of tools.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance of Messrs. Stan Black, Ron Brackett and Phil Rockwell of the Civil Engineering Laboratory, Port Hueneme, California, Mr. Howard Wheeler of the Naval Undersea Center, San Diego, California, and LCDR Thomas E. Berghage of the Naval Medical Research Institute, Bethesda, Maryland, for their assistance in preparation of the outline of human factors information requirements which served as a basis for the report.

The assistance of the librarians of the following activities is also gratefully acknowledged:

Battelle Memorial Institute
Columbus, Ohio

John Hopkins University
Baltimore, Maryland

Naval Coastal Systems Laboratory
Panama City, Florida

Pacific Missile Test Center
Pt Mugu, California

Undersea Medical Society
Bethesda, Maryland

BACKGROUND

We have approached the diver tool information requirement problem by outlining the requirements for information, disregarding the availability of such data. There was no previous list of the information requirements of underwater tool designers, so the Information Requirements Outline represents the biases of the author's consulting group.

The reports which were located address the human factors or human engineering aspects for diver tool design and a great deal of information in related areas of physiology, diving medicine, ergonomics, human engineering and engineering. The reports listed in the Annotated Bibliography are not necessarily exhaustive of related literature, but were selected by the authors as being highly pertinent. Reports of very questionable relevance were purposely omitted.

APPROACH

The librarians listed in the "Acknowledgement" section were tasked to prepare bibliographies in the report subject area. Key search words were provided.

A preliminary outline of Human Factors Information Requirements for Diver Tool Design was prepared by the authors. A meeting was held at Port Hueneme, California with personnel from the Civil Engineering Laboratory, Naval Coastal Systems Laboratory, and the Naval Undersea Center in attendance. Each item of the outline was discussed and items added where necessary. The objective was to make the outline as complete as possible, such that all significant items of importance for tool design were included.

Organization of Outline

The general method used was to work from the general to the specific, concluding with individual types of tools such as chain saws and grinders. This was done to remove the necessity of repeating items for each tool, that may have been common to many.

The numbers appearing in the outline to the right of various items refer to the report numbers of reports listed in the Annotated Bibliography which contains information relative to that item. For example, under I.A.(2), Effects of Cold on Grip Strength, numbers 18 and 39 are given. These are the numbers of the reports in the Annotated Bibliography which give information about grip strength as affected by cold.

CONCLUSIONS

It is apparent from perusal of the Information Requirements Outline that much of the available information relevant to underwater tool design is concentrated on the effects of environmental variables on man. Relatively little has been written about specific tools. However, the paucity of written information is not indicative of what is known about design of particular types of underwater tools. Practitioners of diver tool design have an unwritten store of information which is not significant enough to publish in its individual elements, but would be highly useful if collected and presented in a unified report.

The lack of a unified source of information results in unnecessary duplication of effort on the part of individual designers of underwater tools.

This information could be collected and published as the proceedings of a meeting of underwater tool designers. The agenda of such a meeting could include all items of the Information Requirements Outline for which information has been obtained through actual design and field experience. Other missing elements in the Information Requirements Outline may be filled through specific research projects.

RECOMMENDATIONS

A Navy sponsor such as the Office of Naval Research or the Naval Sea Systems Command should task a Navy Laboratory to prepare a unified underwater tool design manual. Emphasis should be placed on the requirements for the design of individual tools and separate classes of tools such as hydraulic. Navy organizations such as the Naval Coastal Systems Laboratory, Naval Undersea Center and the Civil Engineering Laboratory and commercial organizations such as Battelle Memorial Institute, all of which have been active in underwater tool design, should be tasked to participate.

INFORMATION REQUIREMENTS OUTLINE

I. General Considerations in Diver Tool Design:

A. Effects of cold 2, 108, 109, 116, 126, 129, 132

(1) Tactile sensitivity 7, 18, 45, 63, 64, 74
(2) Grip strength, initial & sustained 18, 39
(3) Arm strength, initial & sustained 106
(4) Lift strength, initial & sustained
(5) Whole body cooling and its effect 44, 45, 69, 108, 127, 128, 129

(6) Interpretation of tactile displays
(7) Effects of protective suits & diver heating 108, 116, 117

(8) Mental acquity 9, 12, 18, 63, 109
(9) Combined effects of cold & fatigue 8, 69
(10) Effects on other physiological processes such as vision
(11) Other 108, 109

B. Effects of overheating

(1) Caused by warm water
(2) Caused by protective clothing or malfunctioning of diver heating equipment

C. Impediments to diver vision

(1) Water turbidity (natural or caused by work process) 62, 96, 97, 110

(2) Low light levels 97, 110
(3) Filtering and absorption
(4) Headgear 71, 89, 112
    (a) Peripheral 110, 130, 131
    (b) Distortion 57, 59, 110
(5) Water leaking in mask
(6) Eye irritation caused by dry air
(7) Distortion of perception of size & distance 70, 72, 113
(8) Other

D. Visibility of objects, dials, displays, etc.

(1) Color 91, 93, 94, 97, 105
(2) Configuration 41, 105
(3) Contrast 93, 105
(4) Lighting effects 94, 110
(5) Effects of phosphorescent & flourescent paints 97
(6) Results of dark adaptation 86
(7) Other 43, 89, 90, 96, 97

I. (Continued)

E. Other major factors affecting general diver performance and tool use

(1) Narcosis
(a) Breathing air 10, 11, 40, 61, 114, 127
(b) Breathing helium mixtures
(2) Fatigue
(a) Muscular
(b) Psychological
(3) Psychological stress 10, 16, 19, 40, 112, 124, 131
(4) Relative weightlessness 21
(5) Water viscosity
(6) Surge & current
(7) Ear clearing problems
(8) Breathing excessively dry air
(9) Training & proficiency maintenance
(10) Communication 67
(11) Type of diving equipment used
(12) Other 2, 25, 70

F. General safety hazards

(1) Noise
(a) Impeding communications
(b) Hearing hazard
(2) Dropping of heavy objects on divers
(3) General diving hazards
(a) Equipment related
(b) Diving operation related
1. General
2. Too rapid ascent or descent
(c) Other 76

G. Anthropometry 102

H. Diver load carrying/transporting capabilities

(1) On bottom or swimming 49, 130
(2) As affected by current & object bulk

I. Diver force application capabilities 22, 32

(1) Force direction, (one arm vs two arms) & orientation
(2) Tethered or using hogging line vs free standing 24
(3) Instantaneous & sustained torque countering
(4) Power output
(5) Other

J. Effects of gloves

(1) Material, thickness, and configuration
(2) Wet or wet and oily

I. (Continued)

K. Problems associated with marine growth on work object

L. Tool, tool accessory and/or part locations on diver, tool container, etc.

M. Tool maintenance

(1) General requirements
(2) Customary practices by working divers

N. Tool and task analysis and evaluation

(1) Selection of proper performance criteria 107
(2) Selection of representative working divers, work objects, and environments 107

O. Tool development

(1) Utility of using mockups, simulators, and prototypes
(2) Need for basic design parameter data (rpm, torque,etc.)

II. Considerations in Design of Hand Tools

A. Buoyancy

B. Grip surface

(1) Shape (cross section)
(2) Length
(3) Roughness

C. Safety

D. Relative effects of different tool configurations (wrench examples: box end, open end, nut spinner, speeder, ratchet, etc.)

E. Relative effect of different tool terminations (screwdriver examples: standard, phillips, clutch, and Reed and Prince tips)

F. Relative effect of multiple tool terminations for a given tool

G. Specific problems with particular hand tools 24

H. Special problems working with wet materials

I. Control configuration requirements (as FWD-REV control for ratchet wrench)

J. Effects of design of object to be worked on

III. General Considerations in Design of Power Tools

A. Buoyancy

B. Balance 54

C. Safety Hazards

(1) Hazard analysis
(2) Hazards resulting from use of cutting or abrasive blades, wheels, brushes, etc.
(3) Requirements for "dead man" controls
(4) Compound effects of diving and injury
(5) Excessive fatigue
(6) Need for torque control
(7) Using underwater tools on surface

D. Power supply cables or hoses

(1) Drag 78
(2) Stiffness 78
(3) Buoyancy 78
(4) Configuration (as double hoses vs concentric hoses)
(5) Location

E. Connectors for hoses or cables

(1) Swivel connections
(2) Quick disconnects 34
(3) Configurations

F. Tool torque countering capabilities of divers

(1) Conventional tools
(2) Requirement for longer handles on right angle drives
(3) As a function of footing, tethering, diver buoyancy,etc.
(4) Combined effect of torque & weight

G. Advantages of quick change tool bits and chucks 78

H. Handle location and angle relative to cutting blade or bit

I. Advantages & disadvantages of reversing rotation direction

J. Basic information concerning optimum cutting speeds and cutting tool materials

K. Weight, maintenance, safety and efficiency comparisons of hydraulic, electric, and pneumatic diver tools 133

L. Control recommendations for diver comfort, safety, and efficiency

III. (Continued)

M. Special considerations for zero visibility

N. Need for topside control of tool power

O. Rigging

P. Percussion effects of moving parts

Q. Reasonable diver maintenance expectations

IV. Special Considerations in Design of Hydraulic Tools

A. Oil contamination in water

B. Oil contamination of diving equipment

C. Water contamination in oil

D. Maintenance 78

E. Other 6, 17, 29, 33, 38, 115

V. Special Considerations in Design of Pneumatic Tools

A. Bubbles obscuring vision 26, 54, 55

B. Noise 26, 55

C. Maintenance 26, 55

D. Understanding of depth limitations 26, 55

E. Understanding of physiological effects of pressure pulsations

VI. Special Considerations in Design of Electric Tools

A. Shock hazard protection 4, 54, 56, 77

(1) Effects of voltage, frequency, & AC vs DC

B. Maintenance

C. Abrasive materials in water

VII. Special Considerations for Tools To Be Used in Habitats or Diving Bells

VIII. Specific Types of Tools

A. Impact wrenches 14

(1) Advantages in drilling large diameter holes 78
(2) Importance of one hand operable FWD-REV control
(3) Problems in controlling applied torque
(4) Problems in drilling close tolerance holes

B. Drill motors

(1) Problems in drilling right angle holes
(2) Knowledge of drill bit use rates for different size drills and drill object materials
(3) Need for FWD-REV control
(4) Knowledge of expected hole accuracies 84

C. Abrasive wheel saws

(1) Importance of correct blade rotational direction
(2) Knowlege of blade drag factors

D. Grinders

(1) Need for alternate handle locations
(2) Need for a guard
(3) Need for a guard modification to reduce torque diver must counter 78
(4) Knowledge of diver use problems 78

E. Chain saws

(1) Unique safety hazards
(2) Need for "dead man" control
(3) Optimum blade set vs type and wetness of wood
(4) Need for "dogs"

F. Hull cleaning brushes 67, 84

(1) Unique safety hazards
(2) Need for FWD-REV controls
(3) Need for "dead man" control
(4) Need for speed control
(5) Need for lights
(6) Special configuration requirements

G. Band saw

(1) Unique safety hazards & requirements
(2) Unique buoyancy requirements
(3) Unique handle requirements
(4) Underwater blade changing

VIII. (Continued)

H. Diver powered hydraulic pump 78

(1) Optimum diver muscle combinations
(2) Unique base or attachment requirements
(3) Consideration of volume & pressure of pumped fluid

I. Stud guns 66, 135

(1) Unique sa ety hazards 66, 99
(2) Problems n accurately placing studs 100
(3) Other 2 , 98, 100

J. Rock drills , 35, 36, 80

(1) Optimum ertical bearing loads (weight or feed pre sure)
(2) Indexing angle (ratio of impact frequency to rotati speed)
(3) Need f toque control 32
(4) Unique isibility problems
(5) Chip moval problems
(6) Rock illing vehicles 80
(7) Other 20

K. Lift devi (lift bags or pontoons) 32, 81

(1) Uniq vertical control problems and recommendations 32, 79, 107
(2) Rig ng problems 106
(3) Se ting proper size for load
(4) Ot

L. Explos devices

(1) que safety considerations 13
(2) er placement 80
(3) er 35

M. Weldi and burning equipment 111

(1) y vs wet environment
(2) raining and experience
(3) quipment design 84, 111
(4) perational procedures 84
(5 Need for staging

VIII. (Continued)

N. Nut splitter

(1) Requirement for operational & maintenance instructions

O. Pile cutter

P. Fasteners 37, 38

Q. Hurst Rescue Tool 43

R. Power Sources 27, 30, 72

IX. Underwater Work Vehicles (operated by divers and used essentially as tools, to transport tools or as tool power supplies), Consult with NUC & CEL 31, 73, 134

A. Unique safety hazards 28

(1) At air-sea interface
(2) Control of ascent rate

B. Need for hazard analysis 28

(1) General
(2) Problems working near support craft, etc.

C. Emergency procedures training 28

D. Use of cockpit mockups in development 28

E. Increased problems of working in turbid water

F. Communication problems

G. Instrument and control problems 28

H. Operator training

I. Controls & displays

J. Problems of using umbilicals

K. Problems encountered operating in surge

L. Other

X. Manipulator Controlled Tools 53, 134

A. Visual control problems 46, 51

B. Alignment control problems 46, 48, 50, 51, 52

C. Unique instrument & control requirements 46, 47, 50, 60

D. Operator selection & training 51

XI. Rigging 80

A. Unique object location problems

B. Torque control requirements

C. Problem moving heavy cables or chains

D. Techniques to prevent loss of attachment device parts

E. Communication & verification problems 65

XII. Diver Support Work Platform

A. Control problems

B. Instrumentation problems

C. Dry work area requirements

D. Lighting & communication requirements

REQUIREMENTS FOR ADDITIONAL INFORMATION

The areas where information is largely or completely lacking may be readily obtained from examination of the Information Requirements Outline. We were unable to locate documents which contained information concerning some general areas such as I.B. Effects of Overheating. Information was essentially lacking for design of individual tools and classes of tools.

All of the items listed in the outline were considered important by the authors and participating Navy Laboratory personnel. Sincere efforts should be made to obtain the required data as explained in the Recommendations Section.

ANNOTATED BIBLIOGRAPHY

1. Adolfson, J., "Deterioration of Mental and Motor Functions in Hyperbaric Air", Scan. J. Psychol., 1965, V6, pp 26-32.

The effects of hyperbaric air on manual dexterity and arithmetic calculation capacity were studied in 15 subjects at ambient pressures of 4, 7, 10 and 13 ata at rest, and at 4, 7, and 10 ata during exercise (300 kpm/min). A significant reduction of the performance in both tests was observed at 10 and 13 ata at rest. During exercise in manual dexterity the reduction was significant at 4, 7 and 10 ata and in arithmetic calculation capacity at 7 and 10 ata. At 13 ata (at rest) a number of marked behavioral symptoms were observed, including changes in mood, impairment of conscieousness, disturbance of perception, and deterioration of motor functions. These changes were readily reversible as soon as the pressure was lowered.

2. Anonymous, 1968, "Diving Scientists Test Underwater Work Ability", Ocean Industry, 3(1), pp 23-24.

Tests were used to answer the questions, "How well does man function underwater? What kind of equipment should be developed to make his underwater work more productive? How much work can be done? and What type of work can he do most effectively?

The tests were conducted at water temperatures of 45° and 64°F. Psychomotor, mental, and combination tests were used.

3. Anonymous, "Japanese Develop Sea-Going Bulldozer", Ocean Industry, January 1969, pp 7-8.

An underwater bulldozer, powered hydraulically from a surface craft, is operating successfully in 30 ft. waters. Its Japanese developers are already developing a larger unit for commercial applications. The prototype - capable of operating in water depths of 10 meters - is a conventional 17-ton class bulldozer which has had its diesel engine removed and mounted on the accompanying floating control deck.

4. Anonymous, 1969, "Amphibious Motor Takes On Repair and Salvaging Underwater", Product Engineering, pp 58-59.

The design and utilization of an underwater electrical tool is discussed. The tool has both high and low speed output shafts. The tool is provided with both rotary and linear impactors.

Use of the tool during the "Tektite" project is discussed.

Special provisions are provided for electrical safety.

5. Anonymous, "Underwater Trencher Remotely Controlled, Ocean Industry, May 1974, pp 21-24.

The system was developed by several Japanese manufacturers commissioned by the Japan Society for the Promotion of the Machinery Industry. The unit consists of an explorer robot, a borer, shovel and grab-bucket, a trencher and support systems. These systems work on the sea-bed at depths up to 70 m, remotely controlled from a parent vessel floating on the surface.

6. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia, September 1975 (Rpt. No. 2155), by D. L. Jenkins, et al., "Hydraulic Powered Underwater Tools For The Installation and Maintenance of The Multileg Mooring System".

This report covers the development of hydraulically powered tools for both surface and underwater use in the installation and servicing of offshore tanker mooring and ship-to-shore offloading pipeline systems. The power unit is a gasoline-engine powered hydraulic pump assembly mounted in a container which can be placed on the ground or in a small boat or floated on the surface of the water while in use. Two hydraulically powered winch-hoists are included for use during replacement of the seaward end of the ship-to-shore pipeline. Other components are a light-duty impact wrench, a hydraulic drill, a heavy-duty impact wrench, a disc-wheel grinder, and two cable cutters capable of cutting wire rope of up to 1 1/2-inch and 3/4-inch diameters, respectively. A pressure intensifier is also included to operate the larger of the two cable cutters provided.

7. Army Natick Laboratories, Natick, Mass., April 1972, (AD 756-417), by J. M. McGinnis, "A Human Factors Evaluation of Cold Wet Handwear".

Subjects performed a battery of manual performance tasks (Torque Test, Minnesota Two-Hand Turning Test, O'Connor Fine Finger Dexterity Test, Cord Manipulation and Cylinder Stringing Test, Bennett Hand Tool Dexterity Test) under six handwear conditions; bare-handed, standard leather glove, impermeable glove, leather glove with wool inserts, impermeable glove with wool inserts, and impermeable glove with built-in insulation. Each subject performed the tests under each handwear condition for 14 days at 35°F ambient temperature and this comprised the Dry Glove Investigation. An additional Wet Glove Investigation involved the same tests and handwear conditions and was of four days' duration. On days 2 and 3, subjects immersed their gloved hands into 35°F water for two minutes prior to testing each glove condition while, on Days 1 and 4, there was no water immersion. During the Dry Glove Investigation, the impermeable gloves resulted in superior performance on the Torque Test. For the remaining tests, the bare hand condition resulted in superior performance and the impermeable gloves with built-in insulation resulted in inferior performance compared to the other handwear conditions. Performance level on all tasks decreased on the first day of water immersion, but performance on the Minnesota Two-Hand Turning Test only was adversely affected on both water immersion days. It was recommended that the impermeable glove with built-in insulation be given no further consideration and that the impermeable gloves, with and without wool inserts, be given serious consideration for field use under wet-cold conditions.

8. Baddeley, A.D., "Influence of Depth on The Manual Dexterity of Free Divers: A Comparison Between Open Sea and Pressure Chamber Testing", J. Applied Psychol. V50(1) 1966, pp 81-85.

Using a compression chamber, Kiessling and Maag (1962) showed a decline in manual dexterity at a pressure simulating 100 ft of water. Impairment was slight (7.9%) and was assumed to be of little practical importance. The present study examines this conclusion by testing divers in the water. The manual dexterity and tactile sensitivity of 12 free divers were tested above the surface, and at 10 and 100 ft below the surface. The dexterity test took 28% longer at 10 ft and 49% longer at 100 ft than on the surface, the differences between all conditions being significant ($p < .005$). Tactile sensitivity did not change. Replication in a dry pressure chamber showed an impairment of less than 6%, which though reliable ($p < .05$) was signifacantly smaller than that shown in the open sea ($p < .05$). Conclusions are (a) the impairment of manual dexterity at depth is considerable when tested under water, (b) it is unwise to generalize from pressure chamber experiments to under water performance.

9. Baddeley, A.D., "Cognitive Efficiency of Divers Working in Cold Water", Human Factors, 1975, V17(5), pp 446-454.

The cognitive efficiency of 14 divers was studied during 1-hour exposure to water of 40°F (4.4°C) and 78°F (25.6°C). Reasoning ability was tested using a sentence comprehension task presented at the beginning and end of each test session. Vigilance was tested by requiring subjects to detect the onset of a faint peripheral light during the performance of a two-man pipe assembly task. Memory was tested by requiring subjects to learn a number of "facts" during the dive, with retention tested by recall and recognition on land, after a 40-min delay. Despite a mean drop in rectal temperature of 1.3°F (0.72°C), neither reasoning nor vigilance was impaired. Memory performance did deteriorate, though it is suggested that this may reflect a peripheral context-dependent memory effect. It is concluded that a well-motivated subject may be cognitively unimpaired despite a marked drop in deep body temperature.

10. Baddeley, A.D., and N. C. Flemming, "The Efficiency of Divers Breathing Oxy-Helium", Ergonomics, 1967, V10, pp 311-319.

Eight divers performed an addition test and a screwplate test of manual dexterity in the open sea under four conditions - breathing either air or an oxy-helium mixture and working at a depth of either 10 or 200 ft. Speed of addition was impaired at depth for both air (19.9 per cent) and helium (14.8 per cent), while errors increased only on air (from 5.9 to 21.1 per cent). The manual dexterity test also showed a decrement in speed for both air (46.7 per cent) and helium (31.8 per cent), and air divers lost more screws at depth (11.1 per cent) than at 10 ft (4.7 per cent). While a decrement at depth was expected in the air dives, the considerable impairment shown on oxy-helium dives was not. A further experiment was therefore run in a dry pressure chamber to study the effects of breathing oxy-helium at pressure when the additional stresses associated with deep diving in the open sea were absent. At a pressure equivalent to 200 ft of water, there was a 10 per cent impairment in speed on both the screwplate ($p < 0.01$) and the addition test ($p < 0.05$). It is concluded that the diver's efficiency on either breathing mixture is impaired at depth, but that at 200 ft the helium diver works slightly faster and considerably more accurately than the air diver.

11. Baddeley, A.D., et al., "Nitrogen Narcosis and Performance Under Water", Ergonomics, 1968, V11, pp 157-165.

Eighteen divers were tested four times under water, twice at a depth of 5 ft and twice at 100 ft. They performed three tests - digit copying, a sentence comprehension test and a manual dexterity test. All three showed a significant drop in efficiency at depth. This was small for digit copying (7.9 per cent) and manual dexterity (3.5 per cent), and somewhat larger for sentence comprehension (15.3 per cent). In all three cases the drop in efficiency was approximately the same as found at the equivalent pressure in a dry pressure chamber. This contrasts with previous results where impairment in the open sea has been considerably greater than in a dry chamber. Possible reasons for this discrepancy are discussed and it is suggested that level of anxiety may be a crucial factor.

12. Baddeley, A.D., et al., "Cognitive Efficiency of Divers Working in Cold Water", Human Factors, 1975, V17(5) pp 446-454.

The cognitive effiency of 14 divers was studied during 1-hour exposure to water of 40°F (4.4°C) and 78°F (25.6°C). Reasoning ability was tested using a sentence comprehension task presented at the beginning and end of each test session. Vigilance was tested by requiring subjects to detect the onset of a faint peripheral light during the performance of a two-man pipe assembly task. Memory was tested by requiring subjects to learn a number of "facts" during the dive, with retention tested by recall and recognition on land, after a 40-min delay. Despite a mean drop in rectal temperature of 1.3°F (0.72°C), neither reasoning nor vigilance was impaired. Memory performance did deteriorate, though it is suggested that this may reflect a peripheral context-dependent memory effect. It is concluded that a well-motivated subject may be cognitively unimpaired despite a marked drop in deep body temperature.

13. Bartholomew, C.A., etal., "Underwater Explosive Cutting in Ship Salvage", IEEE Ocean, 1975, pp 592.

The sensitive use of explosives in ship salvage operations is described with a brief review of the physical phenomena involved in underwater explosive cutting. Specific problems encountered in the design and use of shaped charge cutters are identified; actual on site improvisations are summarized from recent and current case histories of ship salvage involving extensive explosive cutting. Prime factors leading to successful results with explosives in ship salvage are considered and clarified.

14. Battelle Columbus Laboratories. Operation and Maintenance Instructions, Hydraulic Impact Wrench, Columbus, Ohio, July 1975. (Contract Number N00024-75-C-4175).

The manual contains operating & maintenance instructions for a commercial hydraulic impact wrench manufactured by STanley Hydraulic Tools. The wrench was modified by Battelle to enhance corrosion resistance, provide pressure compensation for sea working depths, and to improve diver handling.

15. Biersner, R.J. & B. J. Cameron, "Memory Impairment During A Deep Helium Dive", Aerospace Med., June 1970, pp 658-661.

Twenty divers performed an associative memory task at three intervals during a saturation dive; once at the surface, a second time at a depth of 600 feet, and a third time during ascent at 100 feet. Memory tested after a 60 minute delay at 600 feet was significantly poorer than 60 minute memory tested on the surface or at 100 feet. It was concluded that the selective impairment resulted from psychological stress rather than helium narcosis, since 5 minute memory was not impaired at 600 feet, and 60 minute memory remained completely intact in several instances. This study provides evidence suggesting that psychological stress may be an important factor in influencing performance at extreme depths.

17. Black, S.A. and Quirk, J.T., Hydraulic Tools for Divers, Equipment for The Working Diver, 1970 Symposium, pp 323-

This paper presents a review of hydraulic tool power systems developed and evaluated at the Naval Civil Engineering Laboratory under the joint sponsorship of the Naval Facilities Engineering Command and the Navy Supervisor of Salvage. Diesel hydraulic and electro-hydraulic power systems, including tools, are discussed with the rationale for their use. The paper further discusses human factors relating to the design and development of safe and effective diver tools.

18. Bowen, H.M., "Diver Performance & The Effects of Cold", Human Factors, 1955, V49(2), p. 445.

The capability of divers was tested by a test battery composed of tests of tactile sensitivity, grip strength, manual dexterity, tracking, assembly of a structure by groups, mental arithmetic, symbol processing, simple problem solving and memory. At a diving tower and a flooded quarry, test data were collected for performance on dry land (control) and at water temperatures between 44° and 72°F. A limited sample of post-dive urine temperatures and skin temperatures were recorded. Divers wore a complete 3/16" wet suit, except that, during the tests, the hands were bare. The results show: hand impairment - losses in tactile sensitivity, grip strength and manual movement; the losses were proportional to degree of cold and exposure time; the losses follow a similar course to skin temperature decrease and hence are considered due mainly to peripheral physiological attenuations; psychomotor impairment - losses in manual dexterity, tracking and group assembly were proportionate to water temperature; mental impairment - losses in mental capability occurred in those cases where the task required intense attention and involved considerable short-term memory; "blocking" effects occurred at the lower temperatures. The causes of the losses in capability are discussed in terms of peripheral and central impairments, in terms of "water" effects and "cold" effects, and in terms of a hypothesis that immersion in cold water serves to distract the diver. Some practical and theoretical implications of the study are reviewed.

19. Bowen, H.M., etal., "Studies of Diver's Performance During The SEALAB II Project", Human Factors, 1966, V8,

Field studies of the three 10-man teams of divers participating in the SEALAB II project were undertaken. During each teams 15-day submergence at 205 feet, psychomotor and vision tests were conducted in the water and a mental arithmetic test in the habitat. Compared to base line performance (dry-land and shallow water conditions), performance on the mental arithmetic test showed no deterioration while performance on the psychomotor tests showed considerable deterioration. Many divers found that their in-water work activities proceeded slowly; among other causes of a more physical nature, concern for ones safety may detract from the attention one gives to the tasks at hand.

20. Brackett, R.L., "Development and Testing of Hydraulic Powered Diver Operated Rock Drill and Sea Floor Fasteners", Ocean 75, 1975, p. 249.

The Civil Engineering Laboratory has developed a hand held diver operated rock drill. The drill is hydraulically powered thus eliminating the percussion and visibility problems associated with the underwater use of pneumatic rock drills. Capable of drilling holes up to 2-1/2 inches in diameter and 18 inches deep, the hydraulic rock drill has been used to install various seafloor fasteners and to provide shot holes for small explosive charges. Underwater testing of commercially available rock bolts produced data which can be used for the design of boat moorings and immobilization of undersea cables and pipelines in various types of seafloor rock. This paper discusses the development and testing of the prototype drill as well as the results of extensive testing of seafloor fasteners.

21. Brown, J.L., "Orientation To The Vertical During Water Immersion", Aerospace Med., March 1961, pp 209-217.

Subjects were immersed in water at a depth of either 18 or 25 feet and then rotated in a tucked position on a rod through 3, 4, or 5 revolutions. Rotation was terminated with the head in one of 4 positions: upright, inclinded forward, down, or back. Upon termination of rotation subjects were directed to point in the up direction, then to nod the head and correct the direction of pointing if necessary, and finally to swim toward the surface. There were errors in direction of initial pointing of as much as 180 degrees. Errors were greatest with the head down or back and least with the head up or forward. Nodding of the head was followed by a consistent improvement in the direction of pointing. There was little indication of any difficulty in swimming in the upward direction. Greater density of the legs as compared to the trunk resulted in fairly rapid vertical orientation of the body upon release of the rod. The results are interpreted to reflect the relative inefficiency of the utricles as gravity sensors when the head is in certain positions. The simulation of zero gravity may be enhanced by utilizing these positions with water immersion.

22. Christianson, R.A., "Thrust Forces in Underwater Swimming", Human Factors, V7, 1965.

Instantaneous and mean static thrust levels were measured for eight underwater swimmers restrained in a submerged force platform. Swimming was examined barefoot and with two types of fins. The main beneficial effect of the fins was to eliminate the substantial negative thrust component associated with barefoot swimming. Higher maximal thrust outputs were achieved with curved fins than with straight-bladed ones. There were also significant differences between barefoot and finned swimming in the relationship of instantaneous thrust to leg position during the kick cycle. Kick rate and foot acceleration were both proportional to thrust ouput, but the relationship depended on diver size and experience.

23. Civil Engineering Laboratory, Port Hueneme, Calif., June 1968, (Tech. Rpt. R 583), "Use of Magnets in Marine Salvage", by J. Quirk & R. L. George.

A study was made for the Supervisor of Salvage, Naval Ships Systems Command, to determine the usefulness of magnets in underwater applications. A literature search indicates that large electromagnets are useful for salvaging ferrous cargoes in shallow water. They are of little value in deep water salvage because of the low payload-to-weight ratio and the difficulty of positioning an electromagnet at the end of a long line. Tests of 6- to 8-pound permanent magnets on a ship's hull showed they had underwater holding forces of 40 to 100 pounds. These values indicate such magnets are useful for securing divers and tools to underwater ferrous objects.

24. Civil Engineering Lab., Port Hueneme, Calif., Dec 1969, (TR R-653), "Diver Performance Using Hand Tools and Handheld Pneumatic Tools", by F. Barrett and J. Quirk.

The Naval Civil Engineering Laboratory, Port Hueneme, and the Naval Missile Center, Point Mugu, Calif., have jointly conducted tests to measure diver performance using hand tools and hand held pneumatic tools. The tools included adjustable pipe and machine wrenches, ratchet and special hand wrenches, screwdrivers and the following pneumatic tools: two drills, a power saw, an impact wrench and a chipper. The initial tests were conducted on land and in a test tank filled with fresh water. Ocean tests using the same tools were accomplished at a working depth of 50 feet. Performance times of divers using the various tools on vertical, deck, and overhead surfaces in the ocean are reported. Performance decrements for in-tank and ocean tests are compared to land-test performance. Difficulties encountered using the various tools, tethering devices, and tool holding and transporting devices are reported and suggestions for improvement are made where applicable. Additional tests conducted in the ocean to determine diver one- and two-arm strength while working on vertical, deck, and overhead surfaces are summarized in the appendix.

25. Civil Engineering Laboratory, Port Hueneme, Calif., June 1970, (TR R 684), "Salvage Work Projects - SEALAB III", by J. Bayles.

The Navy is authorized by public statute to provide salvage facilities to assist both public and private vessels. In keeping with this responsibility, the Supervisor of Salvage, U.S. Navy, is prosecuting a vigorous program to incorporate the latest techniques and equipments into the Navy's salvage forces.

The SEALAB III program, under the direction of the Ocean Engineering Branch, Deep Submergence Systems Project Office, was initiated to advance the state-of-the-art of man's capability to live and work in the deep ocean environment. It was the goal of the Salvage Projects for SEALAB III to demonstrate and field test some of the more important new salvage devices and techniques.

This report discusses the aquanaut familiarization and training phases associated with the Salvage Projects planned for Team Two - SEALAB III, and the modifications to both equipments and procedures as suggested by the divers. Preliminary results are included with recommendations regarding future plans.

Human factors studies were conducted in conjunction with the training phases in preparation for SEALAB III. Goals included assessment of divers performance, the development of improved underwater work procedures, and improvement of underwater equipment design through development of design criteria.

26. Civil Engineering Laboratory, Port Hueneme, Calif., June 1971, (TR R-729), "Technical Evaluation & Diver Held Power Tools", by S. A. Black & F. B. Barrett.

Pneumatic and hydraulic hand-held power tools were evaluated by divers performing realistic underwater tasks. These tasks included drilling steel and aluminum, nut running and tightening,

26. (Continued)

grinding metal, and chain sawing wood. An on-the-site observer monitored diver performance time for each task. Diver skill in effective tool utilization is very important in working underwater. At test depths to 60 feet, hydraulic tools were very effective and practical, while pneumatic tools, although effective, required excessive maintenance. At greater depths, hydraulic tools retain their effectiveness, but pneumatic tools lose effectiveness because of the compressibility of gas. Hydraulic tools generally supply more energy per unit of tool weight than do pneumatic tools; thus, the diver can perform work more rapidly using hydraulic tools.

27. Civil Engineering Laboratory, Port Hueneme, Calif., Aug. 1971, (TN-N-1174), "Submersible Diver Tool Power Sources; Electro-hydraulic and Cryogenic Pneumatic", by S. A. Black.

Two self-contained and completely submersible power supplies for powering diver operated hand held tools are discussed; one power supply operates pneumatic tools while the other operates closed cycle oil hydraulic tools. Operational evaluations performed with Navy qualified divers using hand held tools powered by the modules proved both to be effective submersible power sources. Refinements necessary are delineated.

28. Civil Engineering Laboratory, Port Hueneme, Calif., March 1972, (Tech. Rpt. R 762), "Construction Assistance Vehicle (CAV)", by S. A. Black & R. E. Elliott.

An experimental diver-operated Construction Vehicle (CAV) was designed, fabricated, and evaluated in order to determine the feasibility of and general specifications for a prototype diver work vehicle. The CAV, fabricated from off-the-shelf components, is capable of carrying 1,300 pounds of wet weight cargo between the surface and the ocean bottom work site. The craft's pneumatic and hydraulic power is available to operate hand-held power tools. Over 100

28. (Continued)

test dives were conducted in the ocean, with the craft being operated to a maximum depth of 110 feet. Operational testing proved the CAV to be a safe and effective means for delivering cargo and for powering diver tools. Also, when the CAV was compared to other vehicles, it was determined that the CAV is the only system that provides the working diver with total ocean bottom support. The necessary refinements are delineated, and general specifications for a prototype vehicle are presented.

29. Civil Engineering Laboratory, Port Hueneme, Calif., July 1972, (TN-N-1229), "Hydraulic Tools & Equipment For Underwater Salvage", by G. L. Liffick and F. Barrett.

Extending the U.S. Navy's underwater salvage capability will require improved diver-operated tools and equipment. NCEL (Naval Civil Engineering Laboratory) is conducting a program to develop hydraulic hardware for future underwater salvage operations. Commercially available hydraulic pumps, rigging, load handling and cutting equipment have been evaluated at NCEL to determine characteristic diver performance and mechanical suitability for underwater operation. Manually operated hydraulic pumps were modified and pumped against a load cell to determine reasonable levels of diver exertion. Tests have shown that divers can be utilized as prime movers for small jobs and that some conventional surface hydraulic equipment can be used underwater for reasonable periods of time with a minimum of additional maintenance. Surface hydraulic equipment suitable for underwater operation includes manual pumps, rams, cylinders and several cutters. However, innovative new equipment is urgently required for underwater salvage, particularly for load handling.

30. Civil Engineering Laboratory, Port Hueneme, Calif., Dec. 1973, (TR R-801), "Design Criteria For Power Sources Supplying Underwater Hydraulic Tools", by G. L. Liffick, et al.

The Naval Civil Engineering Laboratory is developing hydraulic power sources for underwater hydraulic tools. Hydraulic power sources driven by diesel and gasoline engines engines and electric motors have been successfully developed and evaluated. The operational testing was conducted by divers utilizing hydraulic tools to work underwater. The criteria for selecting a particular hydraulic circuit and the components for an underwater hydraulic power source are different from those used for designing a hydraulic power source for surface tools. For example, a hydraulic pump's tolerance for salt water and its reliability are generally more important than the pump's volumetric efficiency. Pressure and flow gages must be able to withstand severe mechanical vibration, hydraulic fluid shock, and salt spray corrosion. Hydraulic hose expansion under pressure must be minimized but not at the expense of excessive weight. Hydraulic hose couplings should be easy to couple and uncouple but should not separate when dragged over the side of a boat. Hydraulic fluid must provide adequate lubricity, have a low viscosity in cold water and retard damage to the hydraulic system from intruding salt water. The Appraisal given in the report of the relative merits of different hydraulic circuits and components is based on experience gained during NCEL's power source evaluation program. Final component selection, however, is dependent on the user's particular requirements.

31. Civil Engineering Laboratory, Port Hueneme, Calif., April 1974, (TN-N-1339), "Modification of a Pneumatic Track Drill For Underwater Use By Divers", by G. L. Page.

The Navy often relies on explosive excavation techniques for deepening channels and for implacing underwater pipelines and cables on

31. (Continued)

rock bottoms. To effectively emplace the explosive charges requires holes about 2 3/4-inches in diameter by as much as 20 feet deep. Terrestrial track drills have been used for this underwater drilling, but the equipment has experienced early and frequent failures. In order to alleviate these problems, the laboratory has successfully modified a standard Navy-issue Worthington Model 1290D track drill for underwater use to depths of 120 feet.

Three systems of the basic track drill were modified: (1) the hydraulic system that positions the drifter mast, (2) the pneumatic system, and (3) the track drill frame.

32. Civil Engineering Laboratory, Port Hueneme, Calif., July 1974, (TN-N-1345), "Development of The CEL Salvage, Remote Assiste & Lift Device", by J. Bayles.

This report discusses the need for and development of a diver's life assist device as a part of the Navy's salvage forces program. The device discussed in this report combines the best features of the Hunley-Wischhoefer Remote Recovery System and the family of commercially available diver's lift assist devices. Features of the unit include buoyancy variability, inflatability, messenger capability, and reliability. It is designed to be simple, safe, and economical. A water brake designed for the device proved quite effective as a safety feature in slowing the rate of ascent through the water column.

The assembly was successfully tested in the laboratory and at sea and has been forwarded to the Harbor Clearance Unit in Hawaii for in-service evaluation.

33. Civil Engineering Laboratory, Port Hueneme, Calif., Oct. 1974, (TN N-1358), "Diver Work Systems", by R. N. Cordy.

For the past 7 years the Navy's Civil Engineering Laboratory (CEL) has conducted research and development on diver work systems in support of Navy seafloor construction and ship salvage. Under the sponsorship of the Naval Facilities Engineering Command and the Naval Ship Systems Command the program has progressed from the evaluation of unpowered hand tools through pneumatic and hydraulic powered tools, and diver-operated work vehicles. The current program is investigating controlled methods of excavating rock underwater. These investigations have shown that oil-hydraulic-powered equipment is best for most underwater work. Systems using seawater as a hydraulic fluid offer many potential advantages; however, successful development of a practical seawater-powered motor has not yet been achieved. A variety of operational oil hydraulic power sources and compatible tools have been developed and delivered to operational Navy units. The power sources include hand pumps, surface-tendered diesel driven pumps and submersible electric powered units. These bottom units can be either battery powered or supplied from the surface or from shore via an electrical cable. Operational tools include rotary drills, impact wrenches, grinders, rotary abrasive cutters, cable and barstock cutters, chain saws, jacks, pull cylinders, and rotary-impact rock drills. This program has had an impact on many Navy underwater operations. Because of the availability of these work systems, underwater assignments can be done more rapidly, previously impossible tasks can now be undertaken, and hazards to the diver have been decreased.

34. Civil Engineering Laboratory, Port Hueneme, Calif., Nov. 1974, (TN N-1361), "Test and Evaluation of Underwater Mateable Hydraulic Disconnects For Use in Diver Tool Systems", by R. L. Brackett and A. M. Parisi.

34. (Continued)

The Civil Engineering Laboratory has been investigating hardward and techniques that allow the diver to connect and disconnect hydraulic tools underwater in order to utilize several tools during a single dive. Two commercially available non-air including couplings were tested and evaluated for use as underwater mateable hydraulic quick-disconnect couplings. Tests were conducted at 1-foot, 35-foot, and 75-foot depths. It was found that both non-air including couplings met or exceeded the performance requirements established for underwater mateable hydraulic connectors.

35. Civil Engineering Laboratory, "Hand-held Hydraulic Rock and Masonary Drill for Use By Divers", Techdata Sheet 75-7, Port Hueneme, California 1975.

The Civil Engineering Laboratory has developed a hand-held hydraulically powered rock and masonry drill for use by divers in underwater projects that involve such facets as drilling for explosive placement, moving large rocks, immobilizing cables, establishing mooring points, and obtaining core samples of rock formations.

36. Civil Engineering Laboratory, Port Hueneme, Calif., 1976 in editing, "Hand-held Hydraulic Rock Drill and Seafloor Fasteners For Use By Divers", by R. L. Brackett and A. M. Parisi.

The Civil Engineering Laboratory has developed a hand-held hydraulically powered rock and masonry drill for use by divers in underwater projects that involve such facets as drilling for explosive placement, moving large rocks, immobilizing cables, establishing mooring points, and obtaining core samples of rock formations. The drill has the following characteristics:

Drill weight

In air(no ballast) . . .	34.0 lb
In seawater(no ballast .	18.6 lb
In seawater(with ballast)	49.6 lb

Ballast weight

In air	34.1 lb
In seawater.	31.0 lb

Drill rate	0.75-in.diam. hole at 3.25 in./min(in granite)
Hydraulic input	8 gpm flow at 800 psig(with 50 ft of hydraulic hose)

37. Civil Engineering Laboratory, Port Hueneme, Calif., 1976 in editing, "Fasteners For Use by Divers", by R. L. Brackett and A. M. Parisi.

Observations made during pullout tests of different commercially available rock bolts indicate that the bolts can be used effectively to:

MOVE ROCKS. A stud bolt and eyenut can be installed in a large rock, and with the use of a buoyancy lift device, the rock can be moved underwater. The installation of the rock bolt and inflation of the lift bag take as little as 5 minutes, and the diver has complete control of the relocation operation.

SECURE MOORINGS IN HARBOR AND AT WORKSITES. Two-bolt padeyes and three-bolt padeyes are used. The pullout strength of the padeye configuration is about 90% of the sum of the individual rock bolt strengths.

IMMOBILIZE OCEANOGRAPHIC CABLE. Zinc anodes have been added to provide cathodic protection in this long-term installation.

38. Civil Engineering Laboratory, Port Hueneme, Calif., 1976 in editing, "Recent Developments In Diver Construction Equipment", by R. L. Brackett, et al.

The Civil Engineering Laboratory, Port Hueneme, has been devloping tools and equipment for working divers under the sponsorship of the Naval Facilities Engineering Command and the Pacific Missile Test Center. This paper describes recent advancements in tools, equipment, and techniques to increase the construction diver's capability to perform assigned work functions. Specific items include two oil hydraulic powered rock drills, rock coring equipment, a seafloor rock and coral trencher, a diver held hydraulic powered band saw for cutting cables and pipe up to 4 inches in diameter, mechanical and hydraulic nut splitters and special bolts and tools for

38. (Continued)

blindsided bolting. Techniques and equipment to fasten objects to rocky seafloors using both grouted and non-grouted rock bolts will be represented along with a discussion of the development of an underwater grout dispensing system. Development features of each item will be described along with test results and final operational performance characteristics and limitations.

39. Clarke, R. S., "The Duration of Sustained Contractions of The Human Forearms at Different Muscle Temperatures", J. Physiol., 1958, 143, pp. 454-473.

The duration of submaximal contractions held to the point of fatigue was measured for four subjects after they had immersed their forearms for 30 min. in water at temperatures between 2 and 42°C.

Contractions were longest after the arm had been immersed in water at 18°C, above and below which temperature of the water the duration was shorter. Immersion of the forearm in water at 18°C for 30 min. resulted in a muscle temperature of about 27°C measured halfway between the skin and the center of the forearm.

The maximum tension that could be exerted after immersion of the forearm for 30 min. was the same as the initial value in water at 18°C or more; in water at temperatures below 18°C the tension that could be exerted fell sharply with falling bath (and muscle) temperature, to a value of some 40% (of the maximum in water at 2°C.

The post-exercise hyperaemic response was greater for a given duration of contraction in water at 34 and 42°C than at lower temperatures. The rate of blood flow through the muscle during contractions also increased by a greater amount when the water temperature was higher.

Integrated muscle action potentials showed that at the termination of the contraction there was no difference in electrical activity over the muscle when its temperature was 27 or 35°C; when it was reduced to 20°C there was considerably less electrical activity at the end of the contraction.

39. (Continued)

The implications of these results have been discussed. It is considered likely that as muscle temperature increases above 27°C the rate of metabolism increases and results in the earlier accumulation of metabolites so as to cause fatigue; at muscle temperatures below 27°C a proportion of the more superficial muscle fibres do not contract, as a result of interference in nervous or neuromuscular transmission due to cooling.

40. Davis, F.M., etal., "Diver Performance: Nitrogen Narcosis and Anxiety", Aerospace Med., 1972, V43, pp. 1079-1082.

In two experiments in British waters, 16 divers were tested twice underwater, once at a depth of 3 meters and once at 30 meters. They performed 4 tasks - a sentence comprehension test, a memory test, a simple arithmetic test and a manual dexterity test. All but the memory test show a significant drop in efficiency at depth: in Experiment1; manual dexterity 22%, sentence comprehension 16% and arithmetic errors from 6% at 3 meters to 14% at 30 meters; in Experiment 2: manual dexterity 18%, sentence comprehension 10% and arithmetic errors from 5% at 3 meters to 12% at 30 meters. In all three tests these changes are similar to those from boat-diving experiments in the Mediterranean, whereas manual dexterity impairment is greater than for equivalent shore diving in the Mediterranean, A tentative relationship between the extent of performance impairment of manual tasks at depth and anxiety in divers is suggested.

41. Dunlap & Assoc., Inc., "Modification of The Design of Visual Displays in The Maneuvering Room of Guppy Submersibles", by J. D. Coaxley, et al., Stanford, Conn., Sept. 1949 (AD 642-600).

For purposes of analysis, the displays were divided into two main groups: (A) instruments

41. (Continued)

providing quantitative information of primary importance to the controllermen, and (B) accessory instruments permitting few, if any, quantitative readings. The analysis revealed that: (1) there are many violations of the guiding principles of human engineering. (2) the instruments have not been organized into a system of displays from which the operator may obtain precisely the required information.

42. Dunlap & Assoc., Inc., "Submarine Control By a Single Operator", by C. R. Kelley, et al., Stanford, Conn., Oct. 1953, (AD 643-655).

This report is an analysis of the problems involved in one-man submarine control. It is an attempt to study systematically the submarine control system, assuming there is a single human link between the sensing instruments measuring the submarine's performance and the control surfaces used to minimize errors in this performance.

43. Elliott, R., "New Hydraulic Tool Straightens Out Old Problem", Faceplate, April 1976.

The successful use of the Hurst Rescue Tool in straightening of a propeller of an ARS is described. The tool develops 10,000 pounds of force in its arms. Divers used the tool in shallow water in conjunction with a hydraulic ram.

44. Gaydus, H.F., "Effect on Complex Manual Performance of Cooling the Body While Maintaining the Hands at Normal Temperatures", J. Applied Psychol., V12, Jan-May 1958.

Subjects were tested on complex manual performance tasks under two different conditions. In one the body and hands were cooled simultaneously, and in the other the body was cooled to the same degree while the hands were kept warm. A significant decrement in manual proficiency was

44. (Continued)

observed when hand skin temperature dropped to 50-55°F, but no decrement occurred when hand skin temperatures were maintained at 80°F or higher, despite body surface cooling to 78°F in both cases. It was concluded that hand temperature is a vital factor in fine manipulation, but the body can be cooled to a degree which is distinctly uncomfortable without affecting manual performance if the surface temperature of the hands is maintained at normal levels.

45. Gaydus, H.F. and E. R. Dusek, "Effects of Localized Hand Cooling Versus Total Body Cooling on Manual Performance", J. Applied Psychol. V12, Jan-May 1958.

Subjects were tested on complex manual performance tasks under two different environmental conditions. Under one condition, only the subject's hands were cooled while the rest of his body was exposed to a comfortable ambient temperature. In the other experimental condition the subject worked 'in toto' in a low ambient temperature. The tests were given, in both cases, when finger skin temperatures reached certain predetermined levels. No significant differences were found between performances obtained under the two conditions of exposure; however, the results indicate that performance was impaired when finger skin temperature dropped. The finger temperature seems to have been the primary determinant of manual performance decrement.

46. General Dynamics, Electric Boat Division, Behavioral Cybernetic Theory Applied to Problems in Ship Control and Manipulator Operation in Small Submarines, by A. J. Pesch, Groton, Conn., July 1966 (U-417-66-020).

This paper describes some of the human factors in man-multiloop control systems from the standpoint of Behavioral Cybernetic Theory. Specifically, it addresses itself to problems associated with small submersibles where an

46. (Continued)

operator is required to control the vehicles orientation in a mobile medium. This refers to hovering, trim angle, etc., while interacting with the external environment via manipulator arms and visual observation operations. The use of three-dimensional television systems is evaluated.

47. General Dynamics, Electric Boat Division. Experimental Analysis of Three Types of Position Control For Remote Manipulators, by A. J. Pesch, Groton, Conn., December 1967, (P-417-67-077).

Tests were conducted to compare performance using a manipulation system with three different types of controls: control box, skeletal harness and miniaturized skeletal harness.

Generally, performance using either type of skeletal harness improved by a factor of 2.5 in comparison with the control box and learning time was significantly shorter.

48. General Dynamics, Electric Boat Division. Studies of Operator and Control Systems for Small Submersibles, by A. J. Pesch, Groton, Conn., Feb 1969, (P-417-69-026).

This report describes a series of studies which were performed in order to improve our knowledge and technology in the area of small submersible manipulator and ship control systems. The effort was logically divided into two main areas, manipulators and ship control. The manipulator programs major effort was the development of a new control method which utilizes a concept of rate indexing as a solution to the problems of harness type operation in the limited space available in small submersibles. Modifications were made to our basic miniature harness, which was developed in 1967, to allow limited position control and rate indexing of the position envelope of the external manipulator arm. Additional work was also performed in areas such as: empirical calculations of frequency response requirements, selection of paint colors for underwater arms,

48. (Continued)

experimental evaluation of the Autec manipulator arm's drilling tool performance, and the development of a matrix approach to examine manipulator arm capabilities in reference to type of work, control system complexity, juxtaposed with diver performance.

In the area of ship control the small submersible simulation facility was improved for upcoming training programs (Autec) and ship control system development work. Mockup sections were designed and fabricated for the interior of the simulator. Each section represents a part of a typical small submersible configuration namely control console, viewport simulation, pressure hull shape, and seat mounts. Designs were also completed for a 2' x 2' platform which operates with 3 degrees of freedom to simulate visual underwater approaches for ship control and manipulator work simulations. Finally, preliminary work was performed in the area of adaptive ship control systems for small submersibles.

49. General Dynamics, Electric Boat Division. Diver Performance Measurement: Transporting Neutrally Buoyant Objects and Manual Movement of Heavy Objects, by B. G. Andersen, Groton, Conn., July 1969, (U-417-69-066).

The purpose of the program was to develop and apply measurement techniques to determine a free-swimming diver's capacity to transport objects of varying size and weight underwater. Two experiments were conducted during this phase of the program. The first was to measure a diver's ability to swim with neutrally buoyant objects of varying size to determine the effects of increased drag on a swimmer. The second experiment consisted of an exploratory investigation of a diver's ability to move heavy objects underwater for short distances.

50. General Dynamics, Electric Boat Division. Capabilities of Operators as Divers vs Submersible Manipulator Controllers in Undersea Tasks, by A. J. Pesch, et al., Groton, Conn., June 1970, (U 417-70-043).

The selection and design of underwater work systems is often dependent on the ability of the designer to quantitatively estimate the performance of the proposed systems. The major objective of this research program was to analyze, empirically evaluate, and quantify the capabilities of the human operator to perform applied undersea work tasks as a diver, in comparison to his role as the operator of a manipulator-equipped small submersible. A survey of the literature was made in order to include previous data in the analysis. Little of this data was directly applicable due to difficulties in extrapolating from the dry (in-air) laboratory situation to the cramped submersible operating underwater. Problems such as distorted viewports, submersible reaction, empty visual fields, and poor visibility occurred. As a result, experimental data was collected utilizing a small submersible mockup with an actual viewport looking into a water-filled tank in which the manipulator and task were located. The experiment consisted of typical applied salvage tasks such as sample collecting, rigging and hooking, valve turning, connecting and disconnecting a Hansen quick disconnect, drilling, tapping, threading, and unbolting. These tasks were dissected into common behavioral segments (travel, align, etc.) and performance times recorded. Accuracy measures were taken for each of the tasks and the behavioral segments within the tasks. The work systems under study included divers and various manipulator controls (joystick, variable rate; joystick, fixed rate; and pushbutton, fixed rate).

The results of the experiments showed that, overall, divers were faster than rate-controlled manipulators by a factor of 4. This relationship is highly task-specific however, ranging from 1/1.3 (diver/manipulator) for tapping holes to 1/31 for a close tolerance connect/disconnect task. The advantage of one type of manipulator control system over another is also highly task-specific.

50. (Continued)

In addition, the relationship between task complexity and manipulator complexity is inverse and not progressive, at least for the rate-controlled devices studied. In short, the study showed that a simple pushbutton controller performed more complex tasks faster than a more complex joystick controller. The addition of variable rate to either the joystick or push-button controller generally improved performance; however, the actual benefits of variable rate control were again task-specific.

51. General Dynamics, Electric Boat Division. At-Sea Operator Performance of Small Submersible Manipulators, by A. J. Pesch, et al., Groton, Conn., Dec 1971 (U413-71-031).

This is one of a series of reports concerning investigations into the capabilities of scuba divers and submersible manipulators for performing undersea work. The report contains a representative summary or literature search of previous undersea manipulator work which indicates, in overview, that the tasks which were successfully performed were more the result of the ingenuity of the operator in utilizing the existing hardware than the result of the hardware augmenting the operator's basic abilities to perform the task. This report concerns the operation of manipulators in an at-sea environment using the Navy Submersible vehicles SEA CLIFF and TURTLE. The tasks under study in this report concerned the recovery of 50-lb lead pigs, cutting 3" electrical bundles, cutting 1" wire rope, drilling 1/2" holes in 1/4" steel plate and interchanging of tools at depth. The major features of the manipulator system studied were: two arms, 7 df (each), pushbutton rate control system, and interchangeable tools. The results of the tests concluded that: at-sea performance time comparison between divers and manipulators recovering 50-lb lead samples showed a ratio of from 1/40 to 1/17 depending on the form of the manipulator tool used; the average time for a manipulator to recover a 50-lb lead sample ranged from 3.0 to 6.9 minutes depending on the type of manipulator jaw used; manipulator arm motion, especially

51. (Continued)

with heavy loads, has a direct effect on the stability of the submersible and is not easily sensed by the operator; the average time for a manipulator to cut cable ranged from 2.4 to 3.3 minutes; operators had difficulty using a cable cutting tool which required close perpendicular alignment to the cable; the manipulators were unable to drill holes in steel plate probably due to problems of alignment, lack of force feedback and training; operators had difficulty connecting the manipulator arm to the tools located in the basket due to location, visual access, and lack of self-aligning features; a major interface between manipulator and vehicle control exists and requires detailed human factors/control system engineering study and development. A program for both the selection and training of Navy manipulator operators is an apparent need. Leading problems include developing the criteria for selection of operators and the definition of facilities for applied training.

52. General Dynamics, Electric Boat Division. Operator Performance With Alternate Forms of Unilateral Position Control For Undersea Manipulators, by A. J. Pesch, et al., Groton, Conn., Sept. 1972, (U413-72-051).

This is one of a series of reports concerning investigations into the capabilities of operators to use various forms of manipulator control in the performance of undersea work. This report describes an evaluation of two forms of unilateral, position control. The forms include a knob-operated control and a harness-operated control. The two controls were evaluated using experienced undersea operators under simulated conditions including in-water visual conditions, use of a submersible viewport, and the cramped interior typical of a small submersible. The results are presented for eight tasks including sample collection, valve turning, hooking and rigging, unbolting, drilling, tapping, threading, and use of quick-disconnect fitting. Results showed that performance using the harness-operated control was approximately twice as fast as the

52. (Continued)

knob-operated control over all the tasks studied. More importantly, the performance time difference was highly dependent on the task being performed. For example, although the harness control was consistently superior for all tasks performance was proportionally better on basic tasks than on complex tasks.

53. General Dynamics, Electric Boat Division. Operator Performance in Undersea Manipulator Systems, by A. J. Pesch, Groton, Conn., Feb. 1973, (U440-73-020).

A system and method for salvaging submerged marine vessels and other submerged objects, according to which a plurality of flexible inflatable containers are disposed in accessible compartments of the sunken object and/or secured to its exterior and inflated until the object is buoyant. The submerged object is permitted to rise progressively in controlled predetermined increments. Rapid upward acceleration of the object due to rapid expansion of the volume of gas in the inflated containers is prevented. When the object reaches the limit of each controlled incremental rise, the buoyancy of the containers is reduced by bleeding air therefrom or otherwise, while still maintaining the object buoyant. Then the submerged object is permitted to rise a further predetermined amount, and the buoyancy of the inflated containers is again reduced. This is repeated until the object is surfaced. This invention relates to a relatively simple and relatively inexpensive system and method for economically salvaging submerged marine vessels and other objects. Hundreds of ships have been sunk, as the result of storms or collisions or otherwise, through the ages. Although many of these ships may contain valuable cargo or fittings and may themselves have considerable salvage value, relatively few sunken ships have been recovered because the great cost of salvaging usually exceeds the value of the ship and its contents. Similarly, many aircraft have been lost due to ditching and off-shore radar and drilling platforms have been damaged and sunk.

54. Hackman, D.J., "Power Tools for Divers", Battelle Research Outlook, 1969, Vol. 1, No. 1, pp 13-16.

The following topics are discussed:

1. Reduction of or adaptation to the developed torque.
2. Development of required torque.
3. Size, weight, and handling.
4. Materials.
5. Avenues for improvement.
6. Design of electrical tools for divers.
7. Prevention of shock.

55. Hackman, D.J., "Electric Tools for Diver Operation", Symposium on Underwater Welding, Cutting and Hand Tools, pp 141-159.

Commercial pneumatic impact wrenches and air hammers were modified for underwater use (by coating them for corrosion resistance, moving the exhaust so it would not interfere with the diver's vision, and using water as a lubricant).

56. Hackman, D. J. and J. S. Gloscow, "Underwater Electric Shock Hazards", J. Ocean Technol. V2(3), 1968, pp. 49-57.

Table of Contents

57. Hiroshi, O., "Underwater Distance Distortion", Human Factors, V12(5), pp. 473-480.

An experiment was conducted to measure apparent distance of a target within arm's length above water and under water. Eight experienced divers and eight novice divers wearing facemasks indicated apparent distances by reaching responses. The viewing conditions were (1) a target and a subject in air environment, (2) a target in water but a subject in air, and (3) a target and a subject under water. Apparent distances were smaller in conditions (2) and (3) than in (1). This difference is interpreted as being due to the dissimilar convergence and accommodation requirements in the various conditions. There was little difference between the experienced and novice divers.

59. Hiroshi Ono, and O'Reilly, J.P., "Adaptation to Underwater Distance Distortion as a Function of Different Sensory-Motor Tasks", Human Factors, 13(2), 1971, pp. 133-139.

Adaptation to underwater distance distortion was investigated as a function of three sensory-motor tasks and exposure time. The tasks differed in terms of the extent to which visual feedback during the reaching response was provided. Eighteen experienced divers served as subjects. Each subject performed the three sensory-motor tasks and also observed another subject performing the tasks. Underwater distance perception was measured after each sensory-motor task and observing period. Adaptation occurred when the subjects performed the tasks but not when they were observing. The different sensory-motor tasks produced different amounts of adaptation. An argument is made that visually predirected reaching responses (no feedback) would produce greater adaptation than visually guided (feedback) reaching responses.

60. Jones, Robert A., "Manipulator Systems: A Means for Doing Underwater Work", Naval Engineer's Journal, Feb. 1968, pp. 107-118.

Various design considerations are discussed. Limited information is provided for the following terminal devices for use with submersible work vehicles: Cable cutter, various types of hand-like devices, stud gun, centrifugal pump, drill, impact tool and a saw tool. Recommendations are made for controlling and monitoring the manipulation and terminal devices.

61. Kiessling, R.J. and Maag, C.H., "Performance Impairment As A Function of Nitrogen Narcosis", Journal of Applied Psychol., 1962, Vol. 46, No. 2, pp 91-95.

The effects of nitrogen narcosis on the performance of several tasks was studied. 10 Ss were trained to a constant level of performance in a choice reaction time test, a motor coordination test, and a reasoning test. The amount of impairment was determined as a function of increased partial pressure of nitrogen, equivalent to 100 feet of sea water. The results indicated: (a) significant decrease in performance for all Ss on all tests when compared with their individual sea level efficiencies; (b) a position relationship between degree of impairment and the complexity of the task; and (c) an initial loss in efficiency as pressure increased, with this level of impairment remaining relatively constant with increased duration of exposure.

62. Kinney, J.S., et al., "Effects of Turbidity on Judgements of Distance Underwater", Perceptual & Motor Skills, 1969, V28, pp. 331-333.

Judgments of the distance of an underwater target at various locations were obtained as a function of water-clarity. When the target was chose to S, its distance was underestimated. Judgments changed to overestimation as the actual physical distance was increased. Estimates were invariably greater in turbid water than in clear water. These data resolve the apparent conflict between expectations from optical considerations and actual distance estimates made in natural waters.

63. Kowal, J.P., "Cold & The Diver", Sea Frontiers, Jan.-Feb. 1970, pp. 42-47.

Tests were conducted to determine the effects of cold on divers mental performance and manual dexterity. Comparisons were made of performance on the surface and in the water at temperatures of 45° and 64°F.

The major cold effects occur where the water temperature is less than 55°F and when the diver is dressed in a normal 3/16" wet suit and is immersed for up to 30 minutes.

64. LeBlanc, J.S., "Impairment of Manual Dexterity in The Cold", J. of Applied Physiol., July 1956, V9(1), pp. 61-64.

In an attempt to estimate the factors involved in manual dexterity impairment observed in the cold, the following has been found. When the fingers alone were cooled, performance of tests involving little movement of the joint was only slightly enhanced, whereas the impairment was large when the joint movements were increased. This is interpreted as additional evidence to the hypothesis that the increased viscosity of the synovial fluid is a factor in decreasing finger dexterity in the cold. However, this is not the only factor since cooling of the arm, even when the hands are kept warm, also caused a large decrement in finger dexterity.

65. Leggiere, T., "Sound Localization and Homing of Scuba Divers", Marine Technol. Society J., March-April 1970, pp. 27-34.

Several subject-divers were studied for their ability to point to or locate a transducer emitting a sinusoidal, pure tone forty feet away in shallow water. Various frequencies, signal strengths, and pulsing formats were tried and experiments were run with the skull masked by a foam neoprene hood. Slight

65. (Continued)

improvement in pointing performance was detected at the lower frequencies but none of the trials revealed any large improvements in the binaural effect. In 350 trials of all types, a standard deviation of pointing error of 58 degrees was found.

In 20 homing trials the subject swam to the transducer 12 times but the divers noted that when they were oriented to the bottom plane, homing was always possible. It is concluded that a weak binaural ability exists with scuba divers and that a sonic, scuba emergency beacon is possible and probably practical.

66. Lewis, C.A., "Velocity Power Tools", Symposium on Underwater Welding, Cutting, and Hand Tools, pp 114-131.

Both light and heavy duty tools were developed. The various available types of projectiles and ammunition loads are discussed.

67. Liffick, G.L., et al., "Diver Tools", Symposium Proceedings, The Working Diver 1974, Columbus, Ohio, March 5-6, 1974, pp. 125-143.

The Supervisor of Salvage has recently provided hydraulic diver tool sets to fleet activities. This paper describes the equipment provided, training program, and the early work experience. Also covered is recent Navy experience in sonar dome cleaning including a description of hydraulic powered and pneumatic powered systems with a brief discussion of brush design.

68. Lockhart, J.M., "Effects of Body and Hand Cooling on Complex Manual Performance", J. Applied Psychol. 1966, V50(1), pp. 57-59.

Twelve U.S. Army enlisted men were tested on 3 manual tasks, knot-tying (KT), block-stringing (BS), and block-packing (BP), under 4 conditions: (a) Control-Mean Weighted Skin Temperature (MWST) 90.0°F, Hand Skin Temperature (HST) 93.0°F, (b) Cold Body-MWST 69.0°F, HST 90.4°F, (c) Cold Hand-MWST 85.8°F, HST 45.7°F, and (d) Cold Hand-Body--MWST 68.5°F, HST 45.8°F. The 3 cooling conditions had a differential effect across the 3 tasks. Cold Body was the only condition that did not result in significant decrements for all tasks. Knot-tying was unaffected by body cooling. The results were interpreted in terms of the differential effect of cooling the hand or body upon various aspects of complex manual performance.

69. Lockhart, J.M., "Extreme Body Cooling and Psychomotor Performance", Ergonomics, 1968, V11(3), pp. 249-260.

In a series of experiments on the effect of body cooling (the lowering of Mean Weighted Skin Temperature (MWST) while maintaining normal Hand Skin Temperature (HST) on psychomotor performance, the following results were obtained. (1) Block-stringing (BS) and block-packing (BP) performance decreased linearily across levels of body cooling (MWST's of 78°, 74°, 70° and 66°F). (2) Body Cooling (MWST-70°F) affected steadiness-aiming (SA) performance, but did not affect performance on the Craik screw task, the Purdue pegboard assembly (PA) task and the two-plate-tapping task. (3) The effect of level of body cooling on SA performance was similar for fast and slow cooling rates. Significant BS and PA performance decrements occurred only under the low level (70°F MWST) and slow rate (90 min. exposure) condition. (4) Increasing the duration of exposure for 20 and 40 min. after a given MWST condition was attained resulted in significant decreases in BS performance relative to the control condition. The significance of the above findings to the problem of alleviating cold-exposure-induced performance decrements is discussed.

70. Luria, S.M., McKay, C.L. and Ferris, S.H., "Handedness and Adaptation To Visual Distortions of Size and Distance", Journal of Experimental Psychology, 100(2), 1973, pp 263-269.

Both before and after 15 min of adaptation under water, 20 right-handed and 20 left-handed or ambidextrous Ss made size matches to standard rectangles and were tested for hand-eye coordination. Nearly all showed a reduction in the amount of distortion to position after adaptation with no significant differences as a function of handedness. In other respects, however, the 2 groups showed great dissimilarities. The results for the right-handers were consonant with previous reports of a negative correlation between magnitudes of adaptation to size and distance, but this was not true for left-handers. The effect of previous diving experience also differed for the 2 groups. Finally, the left-handers consistently showed increased distortion in the perception of size after adaptation, but the right-handers did not. Thus, only the left-handers showed true counteradaptation (increased distortion after adaptation) but only the right-handers showed negative correlations between 2 modalities of adaptation.

71. Luria, S.M., et al., "Vision Through Various Scuba Facemasks", Human Factors, 1974, V16(4), pp. 395-405.

The visual performance using five commercially available facemasks was compared. Measurements were made of visual fields, visual acuity, stereoacuity, hand-eye coordination, accuracy of distance estimates, and accuracy of size estimates at both near and far distances. In addition, the optical properties of the masks were measured and the susceptibility of each mask to fogging was tested. There were significant differences among the masks for every visual process tested. Some masks were superior for one purpose and inferior for another purpose. For example, the mask which had lenses designed to compensate for the optical distortions found underwater improved size and distance estimates and hand-eye coordination, but degraded acuity and stereoacuity. The results were not explained on the basis of differential susceptibility to fogging.

72. Macnair, E.J., "Closed Cycle Diesel Engines for Underwater Power", SAE Intersociety Energy Conversion Engr. Conf., Boston, Mass., Aug. 1971, pp 577-586.

Diesel engines can be operated under water at continental shelf depths on stored oxygen with recycled cooled exhaust as diluent. By this means, considerably longer submerged endurance can be achieved than from a lead-acid battery of the same weight and bulk, and the engine can also operate on the surface breathing air if required. The paper describes development work on this system in the UK.

73. Mardesich, J., "The Design and Construction of an Underwater Dredge", Earthmoving Industry Conference, Peoria, Illinois, Society of Automotive Engineers, April 1971.

The world's first underwater dredge is at work successfully replenishing badly eroded beaches in Florida. Existing off-the-shelf components have been utilized in the underwater dredge, extending dredging techniques where surface dredges have not been able to operate because of wind and wave action.

74. Mills, A.W., "Finger Numbness and Skin Temperature", J. Applied Psychol., V9, July-Nov. 1956.

The tactile discrimination of the right index fingertips of men exposed to a cold environment was found to decrease with the skin temperature of the same area. The measure of the tactile discrimination was minimum separation between two edges at which they could be discriminated as two. The log of this separation was inversely proportional to the skin temperature between 0° and +33°C. If the finger was rewarmed by a phase of spontaneous vasodilatation, which generally developed after about 15 minutes of exposure to -18° to -23°C, tactile discrimination recovered with the rise in skin temperature. If spontaneous rewarming did not occur at that temperature, frostbite usually ensued.

75. Montagne, W.E. and S. F. Strickland, "Sensitivity of The Water-Immersed Ear to High and Low Level Tones", J. of Acoustical Soc. of Amer. 1961, V33, pp. 1376-1381.

Two experiments are reported regarding man's sensitivity to waterborne sound. The first study investigated the threshold sensitivity to tones of 250, 500, 1000, 1500, 2000, 3000, 4000, and 6000 cps and the attenuation due to the diver's hood. The second experiment obtained data on the "tolerance" to a high intensity tone of 1500 cps.

The sound-pressure level needed to reach threshold in water is about 40-70 db higher than the MAP threshold in air. The greatest loss in sensitivity occurs in the regions of greatest air sensitivity. The diver's hood was found to provide about 20 db or more of attenuation of underwater sound at frequencies above 1000 cps.

The "tolerance" limits for hoodless divers is approximately 174 db re 0.0002 dyne/cm^2. When wearing the hood divers were able to tolerate at least 180 db, the system's maximum output. Above 165 db all divers reported some distortion of the visual field.

76. Moore, A. P. & K. Masubuchi, "Metal Joining in Deep Ocean", IEEE Ocean, 1975, pp. 578-583.

Needs, diving system limitations and pressure related technical problems are considered in an examination of deep ocean metals joining technology. Methods will soon be needed to repair structures at depths exceeding 300 meters but existing arc welding processes are limited in depth by pressure effects acting both on the diver and on the arc. Joining devices being developed for salvage operations are not constrained by diving considerations but are not adequate for most repair and construction work. New processes suitable for remote operation yet versatile enough for practical application are needed.

77. Naval Coastal Systems Laboratory, Analysis of Electro-shock Circuit Configurations Relative to Underwater Cutting and Welding, by F.A. Blanchard & M. W. Lippitt, Panama City, Florida, April 1976, (NCSL 278-71).

An analytical study of the electroshock circuit configuration of the diver using electrically powered tools was attempted considering normal and failed modes of various diver equipments, including arc cutting and welding, and AC powered hand tools.

78. Naval Coastal Systems Laboratory. Navy Diver Tools, Development and Evaluation, by F. B. Barrett, Panama City, Florida, May 1976, in editing.

The primary purpose of the report is to present available data concerned with the suitability of selected Navy diver tools for Fleet use. The objective is to gain official service approval for Fleet procurement and use of the tools. However, the report should be of general utility to those concerned with the development and evaluation of diver tools.

79. Naval Explosive Ordnance Disposal Facility. Evaluation of a Lithium Hydride Gas Generator To Inflate Underwater Lifting Balloons, by B. S. Poe, Indian Head, Md., December 1973, (NAVEODFAC Tech. Rpt. TR-154).

Underwater ordnance lifting equipment currently available is depth limited and does not fulfill magnetic requirements. Consequently, a metal hydride gas generator was tested as a nonmagnetic inflation source for the MK 2 Mod 1 Flotation Bladder.

This report outlines systems operations and compares the present compressed air system used by the Explosive Ordnance Disposal (EOD) community with a newly developed hydrogen gas generating system. Fuel considerations, tests conducted, and hazardous considerations of the chemical gas generator lifting bag system are reported in the appendixes.

Test results show that a chemical gas generator can be used successfully as an inflation source for underwater lifting balloons.

80. Naval Facilities Engineering Command, Washington, D.C. 1971, Ocean Construction Experience Devolving from Project AFAR.

Project AFAR incompasses the construction, installation, and operation of the Azores Fixed Acoustic Range. Some of the underwater tasks accomplished follow:

1. Site survey using the PISCES III, a manned submersible vehicle.
2. Diver use in underwater rigging.
3. Underwater cable laying.
4. Rock drilling by divers using hand tools and a track drill.
5. Placing of explosives.
6. Underwater inspection
7. Cable protection by utilization of diver placed split pipe.

81. Naval Medical Research Institute. A Self Contained Load Handling Pontoon, by K. J. Konda, Bethesda, Md., May 1973 (Rpt. No. 4).

To increase dive safety, endurance, and performance, and to measure dive work in assembly projects, a self-contained load-handling pontoon was developed. The pontoon is light and small enough for one man to handle, yet big enough to carry a good pay-load. It enables a diver to lift a heavy object, move it from point "A" to point "B" in complete safety, and to control the object's up-and-down movement within a matter of inches. Testing results and specifications of the pontoon are discussed; recommendations for improving future models are made. This self-contained load-handling device should significantly extend the performance capability and safety of the working diver.

82. Naval Missile Center. Diver Operated Cargo Carrying Vehicle, Use of a Cockpit Mockup as a Design and Training Aid, by F. B. Barrett, Point Mugu, California, June 1971 (ITP-74-9).

The CAV is the first known effort to develop an open, diver operated, cargo-carrying submersible vehicle. As such, many unique design problems existed. The cockpit mockup was fabricated to aid in solving these design problems. The specific objectives were:

1. The mockup must serve for both surface and underwater test and evaluation of instruments, controls, seats, handrails, and other equipment used by the operators.

2. The mockup must be useful in training personnel in vehicle operation and underwater safety and emergency procedures, and serve as such both on the surface and underwater.

3. The mockup must be relatively inexpensive and simple to construct.

The materials were selected for ease in fabrication and suitability for alternate use in salt-water and on land. It was also desirable to have materials which would make the interchanging of instruments, controls, and other equipment fairly simple.

The author, project engineers and vehicle operators were all Navy certified SCUBA divers, as well as enthusiastic sport divers.

All test objectives were successfully met. Additionally, the mockup proved exceptionally effective for emergency procedures training.

A very significant saving in design and operational test time was achieved through use of the mockup and described procedures.

83. Naval Ship Research & Development Center, Swimmer Capabilities Study, by R.K. Johnson and R.H. Payne, Panama City, Florida, June 1970, (NSRDL/PC3127).

The objective of this task was to obtain data on navigational ability and physical capabilities of reasonably well conditioned swimmers in moving water in order to permit more reliable predictions of possible scenarios of swimmer attacks. It is recognized that the motivation of a determined swimmer is an important but indeterminate factor.

84. Naval Ship Systems Command. Underwater Ship Repair, by N. M. Madatov (Russian translation), Washington, D.C., July 1970, (NAVSHIPS Translation No. 1238).

During the operation of ships, it is possible to have a breakdown of the propeller, rudder and other devices, including the bottom and hull fittings; the hull of a ship or vessel may have sustained combat or navigational damage. The problem of the present reference handbook is to instruct and to provide practical advice on how to eliminate the malfunctions of the vitally important devices and systems, how to stop leakage and to repair ruptures in the ship hull while waterborne, without resorting to the aid available at a dock or shipyard.

The individual malfunctions of the units, systems and equipment and also damages to a ship hull can be repaired more rapidly with the use of underwater ship repair and the repair will cost less than during docking since it is expensive for a ship to be drydocked. At the present time, with the dispersed basing of ships, the necessity for repair away from the main repair bases and the docking facilities is growing; therefore, a knowledge of the underwater ship repair techniques is acquiring considerable importance.

The author has described in detail the technological methods and operations of underwater ship repair, including with the utilization of underwater semiautomatic welding and cutting of metals, underwater painting and other tasks, the technique for which has been developed in recent years. A review is made of the effect of the underwater ship repair methods on the expansion of the production potentialities of the ship repair enterprises for providing the repair of the submerged sections of the hull and of the important units on a ship or vessel; he also discusses the sequence of performing underwater ship repair under autonomous conditions by the personnel at the underwater ship repair stations and by the crews on board the ships. He explores the questions of the technical monitoring and safety techniques involved in underwater ship repair. The required reference materials are included in the book.

This reference handbook is intended for the engineering-technical workers, diving specialists, experts and crew members at the underwater ship repair stations, for the crews on ships in the Navy, merchant marine and commercial fleets, instructors, military school students and students at Naval training establishments. It is also of interest for a broad group of readers since it makes one familiar with a promising type of ship repair.

85. Naval Ship Systems Command. Proceedings of The Underwater Ship Husbandry Workshop, by R. E. Elliott, et al., Washington, D.C., September 1975, (SUPDIV Rpt. 4-75).

Underwater Ship Hunbandry encompasses repair, maintenance, and inspection tasks performed by divers as a service to waterborne ships. In our Navy the execution of these tasks is primarily the responsibility of shipyard, tender, and repair ship diving crews. The Supervisor of Diving (SUPDIVE) funds and monitors research and development efforts whose objectives are to upgrade the capabilities of ship husbandry divers through hardware developments and information transfer. The Naval Coastal Systems Laboratory (NCSL), in Panama City, Florida, is the prime laboratory performing ship husbandry R&D for SUPDIVE.

87. Naval Submarine Medical Center. Underwater Visibility of Fluorescent and Non-Fluorescent Paints by J. S. Kinney, et.al., Groton, Conn., Sept. 1965, (Memo. Rpt. No. 65-11).

THE PROBLEM: To compare the underwater visibility of various fluorescent paints with bright, non-fluorescent paints of the same color.

FINDINGS: Fluorescent paints were correctly identified a greater percentage of the time than were non-fluorescent paints of the same color, under all viewing conditions. Among the various fluorescent paints tested, yellows were the most visible.

APPLICATIONS: The use of fluorescent paints should be considered wherever visibility is an important problem for a diver. For example, fluorescent markings on a wet suit should make it much easier to find a companion underwater. Similarly, equipment and underwater hazards could be made more conspicuous by the use of fluorescent paints.

88. U.S. Naval Submarine Medical Center. Estimation of Size and Distance underwater, by S. M. Luria, Groton, Conn., December 1965, (Rpt. No. 462).

A comparison was made of estimates of both the size and distance of unknown objects in air and in water. Estimates were made both by trained SCUBA divers and by randomly selected subjects. A four-inch square target was positioned at five and twelve feet from the subject for the size estimates and at one foot intervals from four to fifteen feet for the distance estimates. The

88. (Continued)

observations in air were made out of doors and the underwater observations were made from a porthole in a submerged tower. It was found that the estimates of size were reasonably accurate in both air and water, but they were somewhat larger in water; the increase corresponded to the increase in the size of the retinal image as a result of the refraction of lifht waves passing from water to air, by the main group of subjects, but not by the divers. The overestimations increased with increasing distance and the variability was greater in water. Similar overestimations of distance were shown to occur in air when the visual cues which are normally present were sharply reduced. It was concluded that, in unstructured visual fields, estimates of distance are generally too large.

89. Naval Submarine Medical Center. Visual Resolution Underwater, by P. R. Kent, Groton, Conn., May 1966, (Rpt. No. 476).

Visual resolution in air and underwater were compared using Landolt Ring targets and a self-luminous, water and pressure proof target mount. SCUBA diving masks were worn during the tests, both in water and in air. Comparisons were also made while viewing above and below surface targets through a periscope from a surface position.

In both instances, visual resolution in clear water was better than in air at the same actual target distance, when apparent luminances were equated for the two conditions. In most cases, the improvement while wearing the SCUBA mask fell below predictions based on the magnification of the target image underwater. The reasons for this were ascribed to fogging of the mask underwater, and the lack of sufficiently small targets for some observers. The difference in resolution between air and underwater viewing through the periscope was nearer that predicted by theory.

90. Naval Submarine Medical Center. Visibility of Colors Underwater, by J. S. Kinney, Groton, Conn., October 1967, (Rpt. No. 503).

PROBLEM: To determine: (1) the most and least visible colors for use underwater; and (2) whether these results are applicable in all bodies of water.

90. (Continued)

FINDINGS: The specific colors which were most visible varied with the type of water investigated, from orange in murky water to blue-green in clear water. Fluorescent paints were always superior to non-fluorescent of the same color and white was the best non-fluorescent. Gray and black were the most difficult to see.

APPLICATIONS: Specific colors are recommended as aids to visibility for use in underwater operations of divers and operators of small submersibles. Other colors are recommended for concealment and combinations are chosen for cases in which color confusions underwater must be avoided.

91. Naval Submarine Medical Center. Underwater Visibility of Colors With Artificial Illumination, by J. S. Kinney, et al., Groton, Conn., October 1968, (Rpt. No. 551).

The visibility of various colors underwater, when viewed under artificial illumination, has been measured in three different bodies of water chosen to sample a continuum from clear to turbid. Subjects were SCUBA divers who observed the colors at night, using a mercury or an incandescent light source. The visibility results show numerous interactions among color, fluorescence, type of light source, and type of water; from them, it is possible to select the optimum combination to be used under a wide variety of conditions. Colors are specified that will (1) maximize visibility, (2) provide the best camouflage, and (3) allow distinct color differences in appearance for use in color coding. These results are summarized in terms of the colors that are most effective for use under various operational conditions encountered underwater.

92. Naval Submarine Medical Research Laboratory, "Field Test of Dark Adaptation of Divers", by Everley, I. and Kennett, W., New London, Conn., July 1949, (AD 368-163).

Data are presented on 120 dives in water of a depth of 15 to 18 feet in which the bottom was very muddy and tide and current conditions such as to make the advantages of dark adaptation difficult to measure. Subjective improvement, however, was reported by all 60 divers. Data are presented on 42 dives in 170 feet of water half of which were by dark-adapted divers who showed definitely measureable improvement in vision and who universally expressed their opinion that dark adaptation improved underwater vision markedly. The advantages of dark adapting divers is more evident on days inw hcih meteorological and other conditions provide low illumination on the bottom. The practicability of dark adapting divers by dark adaptation goggles worn until the diver was 'on bottom' has been demonstrated It was found that once dark-adapted, a diver's vision will remain constant unless radical change: a light intensity occurs.

93. Naval Submarine Medical Center, Effects of Diving Experience on Visual Perception Underwater, Rpt. 612, by Kinney, J.S., Luria, S.M., Weitzman, D.O. and Markowitz, H., 1970.

Measures of a number of visual functions were performed on subjects with varying amounts of underwater experience. All measures of hand-eye coordination revealed a sizable influence of underwater experience, the more extensive the divng history, the greater the visual-motor skill. On the other hand, size estimates under water by men with diving experience differed little from those by men with none. Results for estimation of distances underwater were intermediate, showing some - but not perfect - correspondence with the amount of underwater experience. The data suggest various additions to the training procedures for SUCBA divers which should facilitate their adjustment to underwater distortion.

94. Naval Submarine Medical Research Laboratory, "Judgements of The Visibility of Colors Made From an Underwater Habitat", Report No. 777, by JoAnn Kinney and J. W. Miller, Groton, Connecticut, 1974.

Judgements of the relative visibility of colors were made during the "La Chalupa" dive from an underwater habitation located in 100 ft of Caribbean water. Judgements made with colored targets viewed against the water background were in agreement with previous studies; that is, bright colors were the easiest to see and dark colors disappeared the most readily. However, when the volors were viewed against a light gray background, dark colors were the most visible. It appears that negative contrast under water is superior to positive contrast of the same amount. In addition, small diurnal changes were found with green increasing in visibility and orange decreasing as the day wore on.

95. Naval Training Device Center. Study, Feasibility of Undersea Salvage Simulation, by H. M. Bowen, Orlando, Florida, May 1971, (69-C-0116-1).

The study reviews man's involvement in undersea salvage operations as conducted by the Navy and defines the relevant training requirements.

Naval Salvage Systems are mobilized from specialized and general purpose equipments. The configuration of any salvage system is determined by the salvage task. There are no "standing" salvage systems; rather, there exists a multiplicity of components and personnel of various abilities from which an ad hoc salvage system is mobilized.

95. (Continued)

Divers represent an important capability. However, the work usefulness of divers is attenuated at deeper depths and by the complexity of the required life support systems and other equipment. One-atmosphere submersibles offer an alternative capability.

A considerable variety of surface ships, submersibles, diving systems and underwater tools is available. A descriptive model of the mobilization of these resources at a salvage site is offered. The following recommendations are derived from this descriptive model:

Divers must be trained in water; hence, training tanks are required. Suitable facilties are described.

Underwater systems require the carrying out of complex procedures and skilled tasks; appropriate simulators to train the required skills are necessary.

Salvage, from the point of view of the on-scene commander and his staff, is a problem-solving operation. Training is necessary and may be conducted by means of a model, an on-line computer, and scenarios depicting salvage situations.

96. Naval Undersea Center. Performance Study of Present and Near-Future Diver Viewing Systems, by S. B. Bryant and C. J. Funk, San Diego, California, July 1972, (NUC-TP-302).

This study evaluates the viewing performance and engineering features of present and near-future diver viewing systems. A simple polarization-discrimination system for diver use was tested in San Diego Bay and evaluated. Water characteristics data was recorded to establish system performance in additional locations. Several near-future diver viewing systems were hypothesized, and a computer simulation predicted the performance of these systems in deep ocean, coastal, coastal, and bay water. The effects of multiple scattering were included in the simulation. Finally, all systems were evaluated as functions of beam pattern, power, human factors, safety, reliability, maintainability and operability.

97. Navy Electronics Laboratory. Evaluation of Phosphorescent and Fluorescent Coatings For Equipment Used at Sea, San Diego, California, January 1954, (Rpt. 455, AD #035502).

Tests were conducted using divers to determine the visibility of objects coated with phosphorescent and fluorescent coatings. Fluorescent coatings were found to be unsatisfactory due to relatively short detection distances and the need for ultraviolet light. The use of phosphorescent coatings definitely increased the detection distance. The visibility of different colors and the effect of turbidity and darkness is discussed.

98. Navy Electronics Laboratory. Divers' Body Heat Loss, by J. Beagles and E. Coil, San Diego, California, October 1966, (AD 652-405).

A study was made primarily to obtain data applicable to the design of an optimum protective suit for divers in arctic environments. The experimental method employed swimmers who performed shallow dives in the NEL arctic pool at 30-32°F. Skin temperatures were recorded by the use of suitably located thermistors, and other data were obtained from blood samples drawn immediately before and after each dive. Results suggest that a four-piece foam neoprene wet suit consisting of a 1/8 inch tight-fitting inner suit and a 1/4 inch snug-fitting outer suit along with two pairs of neoprene socks and mittens would provide the optimum combination of protection and mobility for divers in arctic waters.

99. Navy Experimental Diving Unit. Comparative Evaluation of Powder Actuated Stud Driving Tools for Underwater Use, by G. M. Janney, et al., Washington, D.C., Feb. 1959, (AD 780-211).

Powder actuated, stud driving tools were submitted by three different manufacturers for a comparative evaluation. The purpose of this evaluation was to determine the underwater operating capabilities, the relative ease of operation, and the safety characteristics of each of the tools. The evaluation consisted of laboratory type performance tests and a limited subjective evaluation. Two of the tools were found to be satisfactory and were recommended for field evaluation. The other tool was determined to be unsuitable for use by a diver.

100. Navy Experimental Diving Unit. Field Evaluation of a Powder Actuated Stud Driving Tool for Underwater Use, by B. L. Delanoy, Washington, D.C., April 1959, (AD 778-857).

A brief field evaluation of a powder actuated stud drive manufactured by the Mine Safety Appliance Company was made to determine its suitability for underwater salvage and repair use. The tool was found to give satisfactory performance, but was difficult to operate by a diver.

101. Navy Experimental Diving Unit. Memory Impairment During a Deep Helium Dive, by R. J. Biersner, et al., Washington, D.C., June 1970, (AD 715-344).

Twenty divers performed an associative memory task at three intervals during a saturation dive: once at the surface, a second time at a depth of 600 feet, and a third time during ascent at 100 feet. Memory tested after a 60 minute delay at 600 feet was significantly poorer than 60 minute memory tested on the surface or at 100 feet. It was concluded that the selective impairment resulted from psychological stress rather than helium narcosis, since 5 minute memory was not impaired at 600 feet, and 60 minute memory remained completely intact in several instances. This study provides evidence suggesting that psychological stress may be an important factor in influencing performance at extreme depths.

102. Navy Experimental Diving Unit, Diver Anthropometrics, by Beatty, H.T. and Berghage, T.E., Washington, D.C., 1972.

To aid the design engineer in the development of future U.S. Navy diving systems and equipment a comprehensive anthropometric study was undertaken. Fifty-four anthropometric measures, two pulmonary function measures, and three derived body measures were obtained on 100, 41, and 100 U.S. Navy divers respectively. Descriptive statistics and measures of interrelationship are given for each measured and derived variable. The minimum number of anthropometric variables needed was determined by factor analysis. The measures obtained on the U.S. Navy divers were compared with anthropometric data available for the male aviation populations.

103. Navy Medical Research Institute. Self Contained Load Handling Pontoon, by K. J. Conda, et al., Bethesda, Md., May 1973, (Res. Rpt. No. 4).

The developed pontoon is light and small enough for one man to handle, yet big enough to carry a good pay-load. The movement of the object vertically may be controlled within a few inches. Testing was accomplished using a 130 pound pay load, but the system has a capacity of 650 pounds. The pontoon is SCUBA bottle inflated.

104. Norman, D.G., "Force Application in Simulated Zero Gravity", Human Factors, 1969, V11(5), pp. 489-506.

Utilizing zero-gravity simulation techniques, six subjects provided basic force exertion data under various conditions of personal restraints, worksite geometry, and type and direction of forces to be exerted. All data reported were collected with subjects wearing Apollo suits pressurized to 3.5 psig. Current efforts are providing baseline data under 1-g. and 0-g. shirt-sleeve conditions. This study is part of an ongoing program of research on man's role in maintaining advanced space systems.

105. North American Aviation Inc., Underwater Display Legibility as a Function of Display Format, Color, Brightness and Viewing Distance, by R. A. Beam, et al., Anaheim, California, June 1967, (T7-827/020, 675-008).

Information is presented concerning the legibility of underwater displays. Included are the effect of indicia and numeral size, viewing distance, contrast, brightness, color, size and shape. LImited testing was accomplished.

106. North American Rockwell, Space Division. A Study of Work Producing Characteristics of Underwater Operations as a Function of Depth, by I. Streimer, Los Angeles, California, November 1969, (SD-69-712).

The effects of alterations in working depth upon the work producing characteristics of humans performing specific underwater manual tasks were examined. The tasks were:

1. A simple, repetitive rotary task requiring continuous torque production against a fixed resistance in a self-paced manner.

2. A simple, repetitive, discontinuous flexion/extension task requiring the exertion of linear forces against a fixed resistance in a self-paced manner.

The work was performed at two depths; 33 and 66 feet in the open ocean. During work sessions, heart rate and three skin temperatures were recorded. Similarly, techniques were employed which allows measurement of mean respiratory flow volumes and oxygen uptake level.

The results obtained were examined as functions of task and depth. Statistically significant performance differences were found and related to previous study results.

107. Oceanautics, Inc. Diver Performance and Human Engineering Tests, Salvage Equipment Evaluation Program, USN/Makai Range Aegir Habitat, by B. G. Andersen, San Diego, California, Feb. 1972, (OI-TR-72/1-Poi).

I. Introduction
II. Description of the Ocean Floor Salvage Tool Program
III. Performance Measurement Program
IV. Test Results

A. Training and Baseline Program, Point Mugu

1. Load Handling - Move Test Stand
2. Load Handling - Move Tool Box/Manifold
3. Load Handling - Return Test Stand and Tool Box/Manifold
4. Cutting - Hydraulic Open-Center Cutter
5. Cutting - Abrasive Saw
6. Cutting - Enerpac Diver-Powered Hydraulic Pump and Cutters
7. Combination Task - Install Eyebolt
8. Combination Task - Install Eyenut
9. Combination Task - Install Eyenut
10. Combination Task - Install Three-Bolt Padeye
11. Combination Task - Install Three-Bolt Padeye

V. Discussion and Recommendations
VI. Appendix - Detailed Activity Analysis of Scheduled Salvage Tasks

108. Oceanautics, Inc., "Diving Equipment and Human Performance During Diving Operations in The High Arctic", by B. G. Andersen, San Diego, California, 1973.

This report describes the research findings of the underwater human performance program which was conducted in the high Arctic during the Arctic III Expedition. The expedition was a multi-disciplinary project of MacInnis Foundation of Toronto, Canada, involving a number of marine science and

108. (Continued)

engineering projects. The project was carried out at Resolute Bay, NWT, Canada, from 22 November to 22 December 1972. A primary objective of the human performance program was to add to the limited body of knowledge regarding diver performance in Arctic waters. Focus of the program was an evaluation of the underwater construction of the manned underwater work station Sub-Igloo which was assembled at a depth of 40 feet in Resolute Bay. During the period of the project, ice cover over Resolute Bay was 37 inches, with a constant water temperature of 28.5¼F. Surface temperatures ranged between -5 F and 45 F, with wind velocities of up to 35 mph. The performance program also examined the effects of physiological stress on the divers working under the ice. Measures of diver ECG/heart rates and deep body temperatures were obtained using an acoustical telemetry system. An evaluation was also made of the diver and support equipment used during the expedition, including diver apparel, communications equipment, life support systems, ice cutting apparatus, and portable surface structures.

109. Oceanautics, Inc., Effects of Long-Duration Cold Exposure on Performance of Tasks in Naval Inshore Warfare Operations, by Vaughan, W.S. and Andersen, B.G., Landover, Md., 1973.

Eight UDT and SEAL Team personnel participated in a series of 6-hour test scenarios composed of 3-hours in water, 1-hour in air and 2-hours in water. A variety of tasks were performed in the water which were simulations of submersible operator and navigator tasks: depth and heading control, obstacle detection and avoidance, and navigation problem-solving. In-air tasks were simulations of a demolition raid on an inland target. Test scenarios were run in both cold and control temperature conditions. Cold exposure consisted of water temperature of 4.5 C. (40 F) and air temperature of 10 C (50 F) air; control exposure temperatures were 15.5 C (60 F) water and 20 C (68 F) air. Following the 6-hour exposures, divers rewarmed in either a hot-water bath at 40 C (104 F) or in a hot-air van at 38 C (100 F). Three skin temperatures, core temperature and ECG records were taken throughout the exposure and rewarming phases.

Results suggest a first-hour distraction effect of extreme temperature conditions on performance of vigilance and problem-solving tasks. In cold water, performance was significantly degraded relative to the moderate temperature during the first hour's exposure, then recovered to a level of effectiveness comparable to that associated with the moderate temperature. All tasks showed a gradual decrement with time in the water. In-air task performance was less effective following the 3-hour water exposure for both manual and mental tasks.

110. Oceanautics, Inc., An Analysis of Environmental and Perceptual Determinants of Display Legibility Underwater, by W. S. Vaughan, Landover, Md., April 1976.

A common visual task required of Navy diver is quantitative reading, and the typical environmental context for the reading task is dark, turbid water. In those combinations of surface illuminance and operating depth where visible energy is present as a background, the spectral characteristics of the energy will be specific to the turbidity of the water. Coastal Ocean waters are characterized by low concentrations of large-sixed suspensoids, while Harbor waters are defined by relatively high concentrations of small-sized particles. These two kinds of turbidity conditions affect light transmission in different ways. Coastal Ocean water transmits green and yellow/green light energy best, while Harbor water transmitts yellow and orange/yellow energy most effectively.

111. Rollins, H.E., "Deep Water Metal Cutting Torch", Symposium on Underwater Cutting, Welding and Hand Tools.

North American Rockwell Corporation, through it's Ocean Systems Operations, have examined the functional aspects of current working tools and equipment now in use. They found that most tools in existence today were of little or no use in the deep ocean. Outstanding on this list was the complete lack of capability for deep water metal cutting and welding. Present types of underwater cutting torch equipment have limited capabilities to perform work tasks at deep depths.

In deep sea operations such as, rescue, salvage, construction, mining, drilling, etc., a metal cutting and welding capability is not just a requirement, it is a necessity if man is to succeed in his quest of the deep ocean.

This necessity was recognized and a research program was initiated. This program was established to (1) produce a body of information pertinent to marine cutting torch requirements, (2) conduct a detailed analysis of present types of cutting torch equipment, and (3) concentrate on the operational sequences and characteristics required in a deep water cutting and welding torch system. This analysis showed technological advances in metal-cutting fluorine oxidants and in fuels which could provide feasible means for advancing the state of the art in undersea

111. (Continued)

cutting and welding. A self-contained, modular packaged system, fabricated from "shelf item" components, could be designed and assembled. Such a torch, based on a liquid system, could operate at ambient pressure and would only require sufficient additional pressure to force the oxidant and fuel liquids from the container to the torch head. It was believed that a torch using a metal-cutting fluorine oxidant, and sea water as a preheating fuel, could be successfully employed.

North American Rockwell Corporation, Ocean Systems Operations, submitted their findings to NSSC (Naval Ship Systems Command) and entered into an agreement to continue their research and establish the feasibility of a Deep Water Metal Cutting Torch System.

112. Ross, H.E., "Adaptation of Divers To Curvature Distortion Underwater", Ergonomics, V12(4) 1970, pp. 489-499.

A diver's face mask causes 'pin-cushion' distortion for objects seen underwater. The apparent curvature in depth of a straight line was measured for seven divers in air and water before and after a half-hour dive in the sea. Approximately 25 per cent of full adaptation to the optical distortion occurred during the dive, with a corresponding negative after-effect in air.

The apparent curvature of the line was also measured for 16 novices and 15 experienced divers both in air and immediately on entering the water. The experienced divers showed some initial adaptation, while the novices showed none. This result suggests that the experienced divers had acquired a 'situation-contingent' visual response.

113. Ross, H.E. et al., "Size and Distance Judgements in The Vertical Plane Underwater", Psychol. Forsch., 33, 1970, pp 155-164.

Experiments with subjects of varied experience in clear water of Malta showed that divers tend to underestimate the distance of the surface more than that of the seabed. The underestimation is most marked in clear empty water, but disappears with practice. Objects viewed vertically downwards tend to be correctly estimated in size; but this is an underestimate in comparison with the overestimation which normally occurs with horizontal viewing. These effects are similar to the "moon illusion", but are probably due to visual rather than proprioceptive changes in the vertical plane.

114. Shilling, C.W. and W. W. Willgrube, "Quantitative Study of Mental and Neuromuscular Reactions as Influenced By Increased Air Pressure", Naval Medical Res. Bul., Oct. 1937, V35(4), pp. 373-380.

Men exposed to increased air pressures of 5 atmospheres (gage) or above have a definite feeling of stimulation and well-being which they liken to a feeling of "drunkenness". During such an air-pressure exposure, they have an exaggerated confidence in their ability to accomplish a given task, but to the observer their actual accomplishment falls far short of that demonstrated at atmospheric pressure. This failure of accomplishment was noted, associated with emotional distrub ances, in the 1931 deep-diving trials of the British Navy and was reported by both Phillips (1), and Hill and Phillips (2). Behnke, Thomson, and motley (3) wrote a theoretical paper entitled "The Psychologic Effects from Breathing Air at 4 Atmospheres Pressure" in which they described the abnormal reactions of nine individuals engaged in physiological research work under pressure of 4 atmospheres (absolute). Damant (4) also made reference to the change in behavior which men undergo when exposed to increased air pressure. Although much has been written concerning the impaired neuromuscular coordination, the slowed mental activity, and the alterations of behavior brought on by exposure to increased air pressure, no one has reported any quantitative of these changes. The present paper is a report of such a quantitative study.

115. Shourt, J., "Underwater Tools", Marine Technology Society Journal, July-August 1969, pp. 26-29.

The proposal delineates the feasibility of a versatile torqueless underwater hand tool for use in light and heavy construction. The tool uses water in an open hydraulic system that exhausts into the environment. It will perform the following functions: rotation, impact forward thrust, backward thrust and clamping. In addition, the tool case has forward jets, backing jets, and rotational jets for tool positioning.

116. Stang, P.R., "The Working Diver: Performance in Cold Water", Fourth Annual Conference and Exhibit, Marine Technology Society, July 1968, pp. 289-309.

Data on five manual tasks, a task simulating heavy perceptual loading and four physiological measurements was collected on

116. (Continued)

twelve experienced divers during 1 1/2 hour sessions at 50°, 60°, and 70°F. All subjects were run under all experimental conditions. The dives were executed in a tank in 6 1/2 feet of water with the divers wearing full 3/16 inch wet suits and SCUBA equipment. All measures except the perceptual loading task showed a significant drop in performance over time and a significant time-by-temperature interaction. A general characteristic performance curve seen in the manual and perceptual loading tasks was also observed in several of the physiological measurements.

117. Stang, P.R., "Diver Performance in Cold Water", Human Factors, 1970, V12(4), pp. 391-399.

Twelve experienced divers repeatedly performed several representative underwater work tasks for 90 min sessions at water temperatures of 50°, 60°, and 70°F. Time to complete the task was the primary performance measure; choice reaction time, with mental arithmetic as loading task, and four physiological measurements were also recorded. The subjects worked in 6 1/2 ft of water wearing full 3/16-inch thick wet suits and SCUBA equipment. Performance on all tasks except mental arithmetic tended to decrease as water temperature decreased. Most performance measures also showed a significant decrement over time and a significant time-by-temperature interaction. The general trend in performance measures was also reflected in several of the physiological measurements.

118. Stouffer, J.L., "Effects of Training on Human Underwater Sound Localization Ability", J. Acoust. Soc. Am., V57(5), May 1975, pp. 1212.

Experimental evidence has suggested that humans have a moderately functional sound-localization capability underwater; it appeared appropriate to determine if this ability could be improved by training. Signals of 1000 Hz and 25 pps were presented to the subjects at five angles (to the head). Four sets of stimuli were employed: the first and last sets constituted the pre- and post-tests, respectively, and the middle sets were a training procedure where subjects were informed of the actual source location after each presentation. The obtained scores demonstrated a significant increase in correct responses for the 1000-Hz signal; improvement for 25 pps was not as great and did not show statistical significance.

119. Strange, R.J., "System For Salvaging Submerged Objects", U.S. Patent #3,500,785, March 17, 1970.

A system and method for salvaging submerged marine vessels and other submerged objects, according to which a plurality of flexible inflatable containers are disposed in accessible compartments of the sunken object and/or secured to its exterior and inflated until the object is buoyant.

120. Streimer, I., "Human Performance Characteristics in a Complex Manual Task Underwater", Human Factors, 1972, V14(1), pp. 95-99.

Subjects performed a battery of manual performance tasks (Torque Test, Minnesota Two-Hand Turning Test, O'Connor Fine Finger Dexterity Test) under six handwear conditions bare-handed, standard leather glove, impermeable glove, leather glove with wool inserts, impermeable glove with wool inserts, and impermeable glove with built-in insulation. Each subject performed the tests under each handwear condition for 14 days at 35°F ambient temperature and this comprised the Dry Glove Investigation. An additional Wet Glove Investigation involved the same tests and handwear conditions and was of four days' duration. On Days 2 and 3, subjects immersed their gloved hands into 35°F water for two minutes prior to testing each glove condition while, on Days 1 and 4, there was no water immersion. During the Dry Glove Investigation, the impermeable gloves resulted in superior performance on the Torque Test. For the remaining tests, the bare hand condition resulted in superior performance and the impermeable gloves with built-in insulation resulted in inferior performance compared to the other handwear conditions. Performance level on all tasks decreased on the first day of water immersion, but performance on the Minnesota Two-Hand Turning Test only was adversely affected on both water immersion days. It was recommended that the impermeable glove with built-in insulation be given no further consideration and that the impermeable gloves, with and witout wool inserts, be given serious consideration for field use under wet-cold conditions.

121. Teichner, W.H., "Manual Dexterity In The Cold", J. Applied Psychol., V 11, July-November 1957.

The effects of the cold on manual dexterity were studied by relating performance time on the Minnesota Rate of Manipulation Test to air temperature and velocity, windchill, mean surface skin temperature, digital temperature of the working hand and rate of digital cooling using data from 530 subjects

121. (Continued)

sorted into 14 different combinations of air temperature and wind for an exposure period of approximately 60 minutes. Air temperature and windchill were found to increase performance time significantly; wind velocity did not have a significant effect by itself; mean surface skin temperature was slightly, but significantly, inversely correlated with performance time only for nude men; digital cooling rate and digital temperature were not demonstrated to be related to performance time.

122. Teichner, W.H., "Reaction Time in The Cold", J. Applied Psychol. V42(1), 1958, pp. 54-59.

Visual RT's were elicited from 620 soldiers sorted into 14 different groups representing a variety of ambient temperatures, windspeeds and windchills. Included were two groups at 60°F, five mph, one of which was nude and the other lightly clothed RT was measured after 45 min of exposure and again following a short, mild exercise, after 65 min. of exposure. In addition, mean area-weighted skin temperatures were obtained. The following conclusions drawn from the results apply to the effects of the cold on "non-acclimatized" and/or "non-habituated" men, not in phyiological distress:

123. Tisch, F.P., "A Split Nut for Underwater Application", Symposium on Underwater Welding, Cutting and Hand Tools, pp 132-140.

The advantages of the split nut for underwater work follow:

(1) Absence of torque or end load to effect a fastened assembly or remove same

(2) The fastening of objects can be done quickly using no more than a hand wrench

(3) The opened nut will pass over the end threads of the bolt, the threads of which may be readily damaged by direct contact with other objects or covered with marine growth.

(4) Fastening can be done in more difficult locations where clearance for tools may not exist

(5) Men can fasten objects quicker where reduced mental efficiency, heavy gloves, or absence of light are a problem

(6) Fastening can be accomplished with one hand allowing the other hand free to grasp a hand hold on the object being fastened.

124. University of California. Underwater Work Measurement Techniques, by G. Weltman, et al., Los Angeles, California, July 1970, (UCLS-ENG-7052).

This report reviews progress for the period February 1, 1969 to January 31, 1970 in the study of underwater work measurement technqieus being conducted at the University of California, Los Angeles.

Research work in this period focused on questions of perceptual narrowing during stress and on complex task performance of experienced divers under adverse ocean conditions. Work begun on computer handling of the Sealab III Scenario was completed, and several publications prepared. This effort is summarized below:

1) Perceptual Narrowing. The objective of this investigation was to demonstrate perceptual narrowing in a "risky" situation without the presence of extraneous physiological change, which accompanied the last diving study. A nonfunctional altitude chamber was refurbished to resemble a pressure facility; descent was simulated realistically by means of hissing air, moving pressure gauges, etc. The deception appeared adequate. Student subjects (non divers) were used; 15 rode the chember to "60 feet", 15 served as controls. The central task was a self-paced automatic presentation of Landolt ring targets; the peripheral task, from which perceptual narrowing was deduced, was a light flash in the periphery of a diving mask (150 msec about 8 times a minute). Measures of anxiety were heart rate and score on the Multiple Affect Adjective Test List (anxiety, depression, and hostility during a specific period).

Central task performance was the same for both groups; but the chamber subjects detected significantly fewer peripheral lights (30 per cent versus 70 per cent; $P = .005$) and anxiety test scores ($P = 0.5$) than the controls; scores on depression and hostility were the same. The anxiety scores indicated a normal state for the controls, and a "mild" anxiety for the chamber subjects. It appeared that anxiety produced by the simulation caused a marked reduction in peripheral attention. This validated the previous study, and reaffirmed our interest in the effect of psychological stress on diving performance.

124. (Continued)

2) Complex Performance in the Ocean. A study conducted in Summer 1968 indicated that unlike novice divers, experienced divers showed virtually no decrement in a complex performance (pipe-puzzle) task between the tank and the shallow ocean (20 feet). The object of the present study was to repeat the examination of experienced divers under more demanding ocean conditions (50 feet, cold water, poor visibility). Nine different teams of two divers each were formed from a subject pool of eight experienced divers. Each team performed at least twice in each environment. Written problems were done in the water before task assembly and after disassembly; the divers logged their own task times. Heart rate was recorded continuously. The diving tank was cooled by means of shading, evaporation, and ice to 58° - 60°F and the water dirtied by blackened diatomaceous earth; the ocean test locale off the Pt. Mugu pier had virtually the same conditions. The Multiple Affect Adjective Test List was administered to each subject before every trial.

Results indicated that the completion times were shorter in the ocean trials than in the tank trials, and that the assembly type errors were also no greater in the ocean than in the tank. Some decrement in "practical" problem solving may have occurred. This tends to verify our previous hypothesis that if there is an "open ocean effect" on experienced divers, its only action is to hurry operations somewhat, which may or may not be detrimental. It also reaffirms the value of tank simulations of ocean work.

3) Heart Rate of Working Divers. Data on heart rate response during underwater work in tropical water was studied at Rangiroa Atoll on experienced divers utilizing Aquadyne swimmable hard hats and associated gear. Divers were engaged in assembling an underwater, heavy duty shark cage and in filming operations in 2-5 knot currents, during night and day operations. The absence of heavy concentrations of sharks to provide a high stress environment was disappointing. Successful runs with 3/4" umbilicals, 300 feet in length, using swim fins or divers boots should add another parameter to our insight into diver response to underwater work states. These divers worked at 50 foot depths in 80°F water with good visibility and generally strong currents over rough coral bottom. Heart rate data was recovered every 5th minute over periods up to 1 hour 40 minutes and is in the process of being evaluated. It is planned that these data will be added to data acquired over the past two years in a published summary of heart rate response of working divers. Values available for tasks ranging from light to heavy will be of interest as "benchmarks" to other investigators. Previously observed rates as high as 160 - 170 BPM suggest that divers do not (or cannot) self-limit energy expenditures to low levels.

124. (Continued)

and measurements taken of heart rate andoxygen consumption (using air returned to the surface). Thrust levels were 9 lb. (minimal), 12 lb (moderate) and 15 lb (heavy). Nine different fins were examined for nine subjects. The results indicate a linear relationship between heart rate and O_2 uptake underwater, which confirms the findings of other investigators. No distinct advantage was discovered for any particular fin type.

4) Sealab III Scenario. A computer program was written to permit translation of the Sealab III Operations Scenario from typewritten form to computer storage. Printout was provided in the original format, but at greatly speeded rates. The principal innovation was in the area of Scenario modification. Under control of the program, the Scenario was modified on the alphanumeric display screen of an interactive computer terminal (TV monitor plus keyboard). This approach to modification proved fast, effective, and easily learned by secretarial help. The system was working well when cancellation of the Sealab experiment halted work on extensions of the basic program. The results of this effort have been published in the Marine Technology Society Journal.

5) Underwater Energy Expenditure. The study of measurement techniques for estimating energy expenditure underwater was continued with an investigation of the energy cost of fin swimming. Our previously constructed thrust platform was used,

125. University of California. Underwater Work Performance and Work Tolerance, by G. H. Egstrom, et al., Los Angeles, California, July 1972, (UCLA-ENG-7243).

This report presents findings of the research efforts for 1971 in the study of underwater work performance and work tolerance conducted at the University of California, Los Angeles. The studies were directed towards the development of performance decrement curves related to the specific variables which affect underwater work. Experiments designed to add to the body of knowledge necessary to the formation of decrement curves were conducted. The experiments examined: (a) the effect of cold-water exposure upon memory, reasoning ability, and vigilance, (b) the effect of depth upon memory, (c) wet vs. dry training for a specific underwater task, and (d) the physiological and performance effects of heliox as a breathing gas in cold water. The corresponding results show that: (a) cold-water exposure impairs memory but not reasoning ability or vigilance, (b) although narcotic impairment to depths of 110 feet were small, material learned underwater is not remembered well on the surface, (c) training underwater for a specific underwater task is preferable to dry-land training, and (d) physiological state changes and performance levels in cold water are not substantially different for heliox as compared to air for a wetsuited diver. These data and the data from the literature are incorporated and presented as framework for the performance decrement curves.

126. University of California. "Underwater Work Performance and Work Tolerance", by G. H. Egstron, et al., Los Angeles, Calfiornia January 1973, (UCLA-ENG-7318).

Purpose: Research efforts focused on establishing a methodology for developing curves which will relate the divers ability to perform to the conditions under which he must work. An extensive literature search was made, and a number of preliminary curves derived from the resulting data. At the same time, several experimental studies were conducted to help fill gaps in the existing data store. These dealt with the effects of cold exposure on two critical areas of diver performance: memory and muscle strength. The following sections describe this work.

Performance Decrement Curves: Despite the generally disordered state of the literature on diving performance, it does seem possible to bring together data from related studies and toestablish generalized curves of performance decrement as a function of various diving conditions. In this initial presentation, sample decrement curves are given for cognitive performance during cold exposure and during psychological stress, for motor performance during cold exposure, for psychomotor performance at a function of hyperbaric pressure, and for several other combinations. Future work will require more careful definition of performance catagories and stress variables, as well as considerable attention to the practical application of the resulting curves. It is expected that an immediate outcome will be the identification of important gaps in the presently available data.

Memory in Cold Water: A previous study conducted at UCLA showed that when divers memorized facts in a prose passage underwater and were later asked about its contents on the surface, recall was significantly worse for cold exposure than for warm, while recognition was about the same for the two conditions. The present study altered the order of presentation as well as the stimulus material. Sets of pictures were memorized on the surface and recalled underwater after cold (43°F) or warm (79°F) exposure. In addition, a specific configuration of the UCLA Pipe Puzzle was memorized and executed following a similar procedure. The results were as before. Recall was markedly degraded by cold exposure, while recognition was essentially unaffected. From a theoretical standpoint, these findings support the dual process concept of memory, and suggest that the adverse effect is due either to the general stress of cold, or to the change of state between memorization and recall. From a practical standpoint, the findings should influence both how divers instructions are formatted and how post-dive reports are obtained.

Memory in Hyperbaric Conditions: A previous study conducted in the ocean suggested that aspects of memory were sensitive to hyperbaric exposure as well as to cold. The present pilot study was designed to test this hypothesis under more carefully controlled conditions. Subjects were tested for recall and recognition of facts in a prose passage memorized before the test exposure after pressurization to 0, 100, and 165 feet in a dry hyperbaric chamber. A brief arithmetic test was also administered. It was found that recall decreased 26% from 0 to 165 feet, with most of the change occuring between 0 and 100 feet. Both recognition and arithmetic, on the other hand, showed no change between 0 and 100 feet, and only a 10% decrease at 165 feet. This suggests that recall is sensitive to the

126. (Continued)

psychological stress of chamber exposure as well as to the narcotic effect of pressure. These findings indicate that when cold in combined with even moderate narcosis in underwater work, the ability of divers to follow instructions or to utilize short-term memory may be severely compromised.

Strength During Cold Exposure: Divers are frequently called upon to exert considerable muscle forces during the course of underwater work. Accordingly, the effect of cold exposure on strength is of great interest. The present study established a methodology for isometric strength measurement on several muscle groups, and obtained preliminary data on dry land and at the start and finish of hour-long underwater exposures in the UCLA tank at 80°F and 43°F. There was a marked decrease in grip strength in both underwater conditions due to the use of neoprene gloves. Otherwise, only shoulder girdle adduction exhibited any apparent detrimental effect of cold exposure, and it was slight. The findings suggest the common 1/4 inch wetsuit offers adequate cold protection in shallow water. At greater depths, however, where suit compression reduces thermal insulation, maintenance of strength capabilities is questionable, and should be investigated.

127. University of California, Los Angeles, Underwater Work Performance and Work Tolerance: Final Report, by Egstrom, G.H. and Weltman, G., 1974.

This is the final report on the Underwater Work Performance and Work Tolerance study conducted at UCLA in the departments of Engineering and Kinesiology in their underwater research laboratories. The objective of the study was the classification of the relationships between selected parameters of diver performance and intervening variables such as cold, narcosis and immersion.

128. Vaughan, W.S. and Maver, A.S., "Diver Performance In Controlling a Wet Submersible During Four Hour Exposures in Cold Water", Human Factors, 1972, V14(2), pp. 173-180.

Six 4-hr., open-sea test trials were conducted with a wet submersible. The purpose of these trials was to assess the effects of long exposure to cold (16.5°C) water on man's ability to perform basic submersible control tasks. The subjects were experienced submersible pilots who had a minimum of 20 hours training prior to the experimental trials. Skin and rectal temperatures were continuously recorded from both the pilot and rider of the submersible. A continuous record of vehicle depth and water temperature was also obtained. The pilot's task was to maintain a prescribed depth while performing a sequence of course changes for a 4-hr. period of submergence. Depth error variance was correlated with pilot core and skin temperature changes over time, and although pilot core temperature fell as much as 1.83°C, no degradation in depth control performance was apparent.

129. Vaughan, W.S., "Diver Temperature and Performance Changes During Long-duration, Cold Water Exposure", Undersea Biomedical Research, Vol. 2, No. 2, June 1975, pp. 75-85.

Twelve Navy divers participated in 4- and 6-hour open-water test trials of a 2-man wet submersible in 6°C water. Skin and rectal temperatures of the crews were continuously recorded and performance measures were taken in three task areas; pilot tasks, sonar-operator tasks, and crew-coordination tasks. Results suggest a complex, task-dependent effect of cold stress from deep body cooling. Rectal temperature change was relatively insensitive to differences in exposure conditions, however, and is probably a poor index of cold stress for use as a correlate of performance degradation between normal and clinically critical values of deep body temperatures.

130. Weltman, G. and Crooks, T.P., "Human Factors Influencing Underwater Performance", Equipment for the Working Diver, 1970 Symposium, Columbus, Ohio, pp 31-51.

This paper summarizes experimental findings concerning the performance capabilities of the working diver. It attempts to establish a unified outlook on underwater work, to assess the relative importance of various skills and environmental factors to actual job completion. The presentation focuses on what might be termed the pressure-independent aspects of performance such as training, psychological stress, the ocean environment, cold, and diver stablization. Narcosis, breathing mixtures, and similar direct pressure effects on performance are not included. Much of the presentation deals with recent studies performed by the Underwater Research Group at UCLA. Accordingly, experimental methodology is discussed along with findings. Of particular interest are the work measurement studies done during Summer 1967 on the shallow water trials of the Divercon I construction project for SEALAB III, which represent perhaps the first full-scale examination of a lengthly and highly complex diving job. These studies yielded not only direct data on performance and physiological response, but also surprisingly concordant responses by the Navy divers themselves to questionnaires concerning significant factors in the task environment.

131. Weltman, G., Smith, J.E., and Egstrom, G.H., Perceptual Narrowing During Simulated Pressure-Chamber Exposure, Human Factors 1971:13(2), pp 99-107.

In this study, 15 male subjects performed a central visual acuity task (Landolt ring detections) and a peripheral light detection task during what they thought to be a 60-ft dive in a pressure chamber. There was no actual pressure change. A 15-man control group performed the same tasks at an outside location. Experimental measures included a posttest anxiety checklist and continuous heart rate recording. The chamber group showed significantly higher anxiety scores and also a significantly higher heart rate throughout the experiment. There was no difference between the groups with regard to correct Landolt detections, although the chamber group responded somewhat slower. Peripheral detection, however, was severely and significantly degraded in the chamber group. It was concluded that perceptual narrowing had been demonstrated as a result of psychological stress associated with exposure to the "dangerous" pressure-chamber.

132. Whittenburg, Vaughan Assoc., Swimmer Delivery Vehicle Operations, by W. S. Vaughan, Landover, Md., May 1972, (AD 521-388) Conf.

I. Overview
II. Submarine/Swimmer Delivery Vehicle Coordinated Mission Capability
III. Effects of Long Exposure to Cold Water
  A. Cold Water Test Operations
  B. Effects on Physiological Condition
  C. Effects on Pilot Performance

133. Whittenburg, Vaughan Assoc., Human Factors Guide For the Design of Diver Operated Hand and Power Tools, by B. G. Andersen, Landover, Md., July 1972, (OI-TR-72/2-SK).

This final technical report describes the results of a research study directed toward expanding the available data base of man's ability to work underwater, by providing human factors data on man's requirements and capabilities as an undersea worker. The report is a basic human factors criteria guide for the design of diver-operated tools and work systems.

Data included were developed and compiled through evaluation of operational diver work tasks, in-the-field observation of diving operations, and survey and review of existing human factors research data.

The document is organized into five major sections: 1) Anthropometry and Biomechanics, 2) Body Restraint and Tethering Systems, 3) Underwater Visibility, 4) Control/Display Criteria, and 5) Human Engineering Considerations for Specific Underwater Tools. The Appendix contains detailed specifications for a selected number of frequently used power tools.

134. Woods Hole Oceanographic Institute, Hand Tools and Mechanical Accessories for a Deep Submersible, by Clifford L. Winget, Wood Hole, Mass., May 1969, (AD 697 294).

The design and construction details for various hand tools and accessories used by manned deep submersibles is presented. The tools require the use of amechanical manipulator, and were designed specifically to improve the scientists capability of obtaining deep ocean geological data and biological specimens. The majority of the tools illustrated are of simple design and inexpensive construction.

135. Young, C., Jr., "Underwater Tools", 6th U.S. Navy Symposium of Military Oceanography, Proceedings, V1, Seattle, Washington, pp. 117-127.

The tools described in this paper all perform relatively simple functions under water. All are hand-held or hand-emplaced, and were designed originally for use at 1000-ft depths or less. Each satisfies a particular, well defined need. From this beginning, what may be anticipated in the future? First, it is expected that variations of these tools will be required to satisfy additional requirements. Remote handling from a vehicle may be needed. This might generate the need for electrical firing systems, modifications necessary to interface with manipulators, and deeper operating depth capabilities. In that connection, most tools described in this paper have been fired. No data exist for depths at which failures might occur due to excessive external pressures. It should not be concluded from data on maximum test depths, that a design could successfully be achieved for that depth although there is every indication of it. Second, more tools to satisfy other relatively simple requirements may be needed. An example is the rapid cutting of metal plates at any depth. Third, fixed tools to perform routine functions on a set time schedule or in response to coded acoustic signals may be required. In fact, remotely controlled valves on underwater oil wells are a reality today. It appears that the list of possible requirements for underwater tools in the future is dependent only on one's imagination. However, it must be concluded that, because of the expenses involved, development efforts should be expended only on those tools for which definite requirements exist.